AD-A103 945 ROME AIR DEVELOPMENT CENTER GRIFFISS AFB NY F/G 20/14
EFFECTS OF ENERGETIC PARTICLE EVENTS ON VLF/LF PROPAGATION PARA--ETC(U)
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RADC-TR-81-82
In-House Report
March 1981

AD A103945

EFFECTS OF ENERGETIC PARTICLE EVENTS ON VLF/LF PROPAGATION PARAMETERS/1978

John P. Turtle
John E. Rasmussen
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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RADC-TR-81-82	2. GOVT ACCESSION NO. AD-A103 945	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECTS OF ENERGETIC PARTICLE EVENTS ON VLF/LF PROPAGATION PARAMETERS/ 1978		5. TYPE OF REPORT & PERIOD COVERED In-House
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John P. Turtle John E. Rasmussen Wayne I. Klemetti		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Deputy for Electronic Technology (RADC/EEPL) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62702F 46001604
11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Electronic Technology (RADC/EEPL) Hanscom AFB Massachusetts 01731		12. REPORT DATE March 1981
		13. NUMBER OF PAGES 147
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

VLF propagation
LF propagation
Ionospheric disturbances
Polar cap absorption events

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a summary of disturbance effects of energetic particle events on VLF/LF propagation parameters as observed by the USAF High Resolution VLF/LF Ionosounder in northern Greenland. Disturbance effects on ionospheric reflectivity parameters, including reflection heights and coefficients, are presented along with data from a riometer, a magnetometer, and satellite particle detectors.

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Preface

The authors thank Royce C. Kahler and Duane Marshall for help with the instrumentation which made the measurements possible, and Jens Ostergaard and Bjarne Ebbesen for the outstanding operation in Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted, and to Jorgen Taagholt and V. Neblo Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.

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Effects of Energetic Particle Events on VLF/LF Propagation Parameters / 1978

1. INTRODUCTION

A compilation of data on the VLF/LF reflectivity of the polar ionosphere during 1978 has been published in previous technical reports.[1-3] In this report, the data for specific periods are expanded in order to give a more detailed presentation of the effects of energetic particle events on VLF/LF propagation parameters. These periods have been chosen to show disturbance effects for events in which the 13.7 to 25.2 MeV proton flux recorded by the IMP 7/8 satellites exceeded 10^{-2} particles/cm^2 sec sr MeV. The propagation data were obtained by the USAF High Resolution VLF/LF Ionosounder[4,5] which provides direct measurements of ionospheric reflection height and the reflection coefficient matrix elements $_{\parallel}R_{\parallel}$ and $_{\parallel}R_{\perp}$.[6] Also included are data on particle flux density, HF riometer absorption, and geomagnetic field intensity.

The VLF/LF Ionosounding Transmitter (Figure 1) is located at Thule Air Base Greenland (76° 33' N Lat., 68° 40' W Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24' N Lat., 69° 20' W Long., Geomagnetic Lat. 89° 06' N). The ionosounding transmissions consist of a series of extremely short (approximately

(Received for publication 20 March 1981)

(Due to the large number of references cited above, they will not be listed here. See References, page 147.)

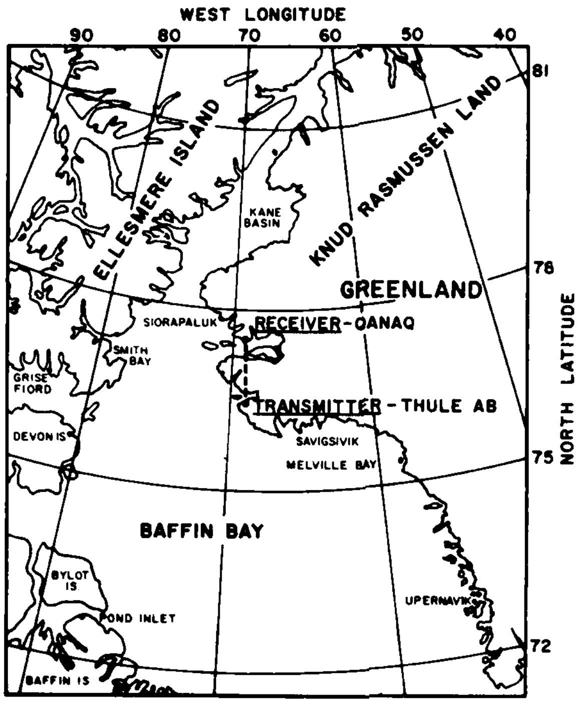

Figure 1. Ionosounder Propagation Path, Thule AB–Qanaq, Greenland

100 μsec) VLF pulses, precisely controlled in time, and radiated from the 130-m vertical antenna (Figure 2a). Orthogonal loop antennas (Figure 2b) are used to receive the two polarization components of the ionospherically reflected skywave signal. One loop, oriented in the plane of propagation, senses the groundwave and the unconverted or "parallel" (∥) component of the down-coming skywave; the second loop, nulled on the groundwave, senses the converted or perpendicular ($\perp$) skywave component. The signal from each of the antennas is digitally averaged to improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. At the receiver, the radiated signal arrives first by groundwave propagation (Figure 3). Due to the extremely short pulse length, this signal has passed the receiver before the arrival of the ionospherically reflected skywave pulse, providing independent groundwave and skywave data. An example of the observed waveforms is given in Figure 4, where the parallel waveform (a) consists of a groundwave propagated pulse, a quiet interval containing low level, off path groundwave reflections, followed by the first-hop parallel skywave component; the perpendicular waveform (b) is also shown. Each of these waveforms

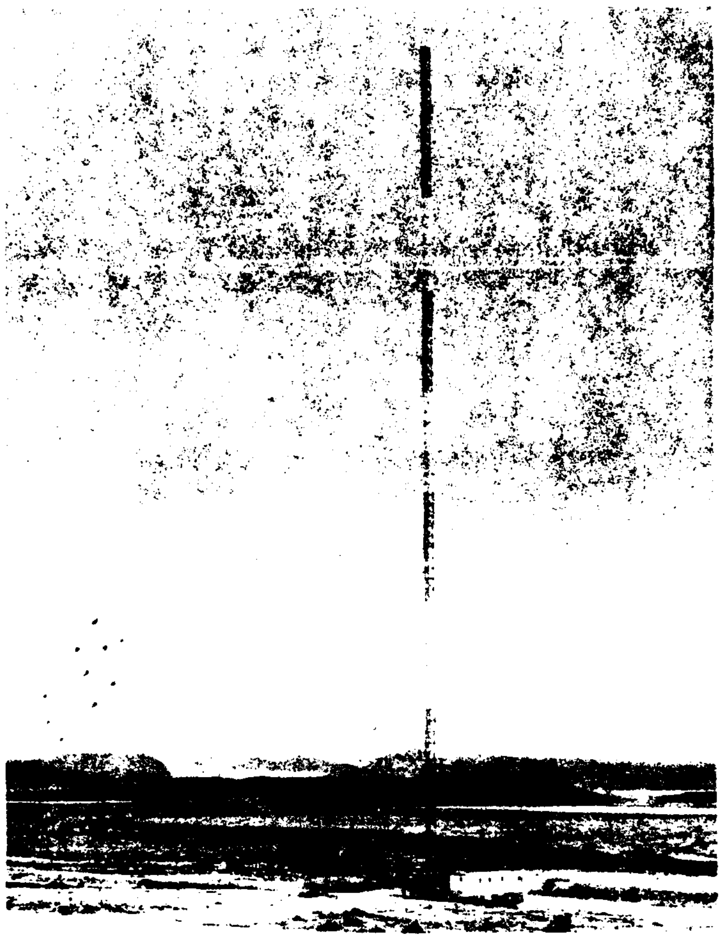

Figure 2a. Transmitting Antenna, Thule AB, Greenland

[illegible] 256 [illegible] average [illegible] points, [illegible] [illegible] are derived by computer processing of the [illegible], with allowance [illegible] factors such [illegible] Section 2.2).

[illegible] spectrum of the [illegible] generally [illegible] operation at higher frequencies [illegible] conditions exist. There is, however, [illegible] signal exists [illegible].

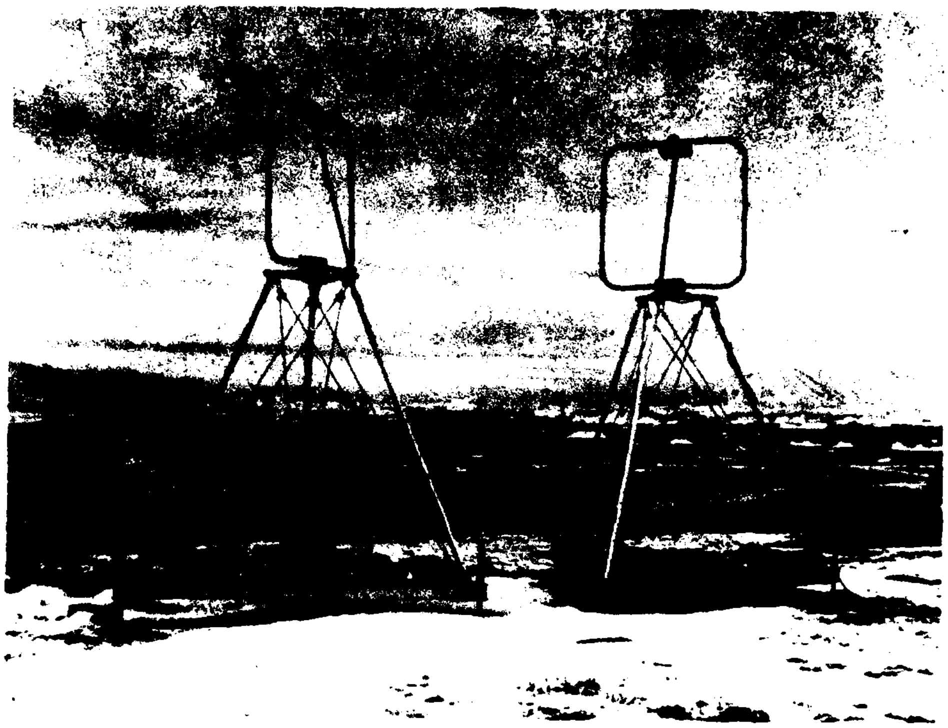

Figure 2b. Orthogonal Receiving Antennas—Qanaq, Greenland

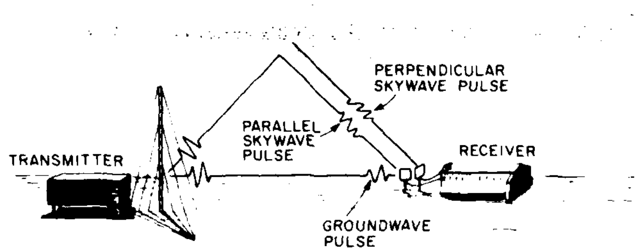

Figure 3. Basic Ionosounding Experiment

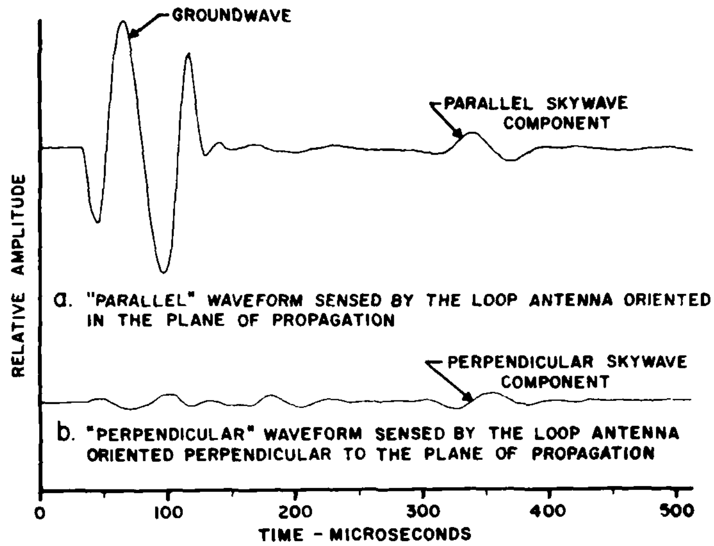

Figure 4. Example of Parallel and Perpendicular Waveforms

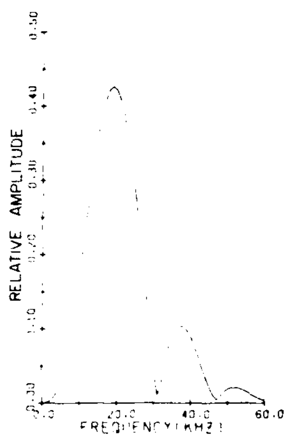

Figure 5. Fourier Amplitude Spectrum of Transmitted Pulses

2. EVENT DATA

The data are presented for each disturbance event in three general formats: first, the observed waveforms are shown in a synthetic three-dimensional display which starts approximately two days prior to the event and covers a fourteen-day period; second, the data are presented in the frequency domain with reflection

heights and coefficients plotted as a function of frequency over the range from approximately 5 to 30 kHz; third, the data are presented as a function of time-of-day. In addition to reflection information, this section contains data on ionospheric absorption, geomagnetic field activity, and solar proton fluxes.

2.1 Observed Waveforms

A three-dimensional waveform display is presented for a 2-week period containing each disturbance event, together with a display of the same 2-week period from a year in which it was not disturbed. For each display, the waveforms were stacked one behind the other in linear time, progressing from bottom to top. Each individual waveform is a 30-min average of approximately 10,000 pulses. The horizontal scale for these plots is linear in time (microseconds), measured from the start of the groundwave. This scale can be used to calculate an effective height of reflection by attributing the time delay between the start of the groundwave and the start of the skywave to a difference in travel distance, assuming a sharply bounded, mirror-like ionosphere. Figure 6 gives a conversion curve for this calculation based on simple geometry and the specific Thule AB—Qanaq, Greenland separation of 106 km. For the disturbance periods, fixed local ground clutter, amounting to only 2% of the groundwave amplitude, was removed to avoid interference with the skywave and improve the appearance of the waveforms.

The three-dimensional displays of the disturbed and normal parallel waveforms are given for each event in Parts A and B of Figures 8 through 23. A plot of the diurnal variation in solar zenith angle for the midpoint of the path appears in Part C. The perpendicular waveform displays are shown in Parts D and E. The time of maximum particle flux is indicated on the disturbance plots.

2.2 Quantitative Reflection Parameters

For each event individual ∥ and ⊥ waveforms were selected in order to show the effects of the disturbance on the ionospheric reflection height and reflection coefficients as a function of frequency. The selected waveforms from the disturbance period are shown in Part F of the data figures, whereas the corresponding undisturbed waveforms are shown in Part G.

2.2.1 REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing this difference to a difference in the propagation distance. The group delay can be defined as the rate of change of phase with frequency as discussed in Lewis et al.[4] For the

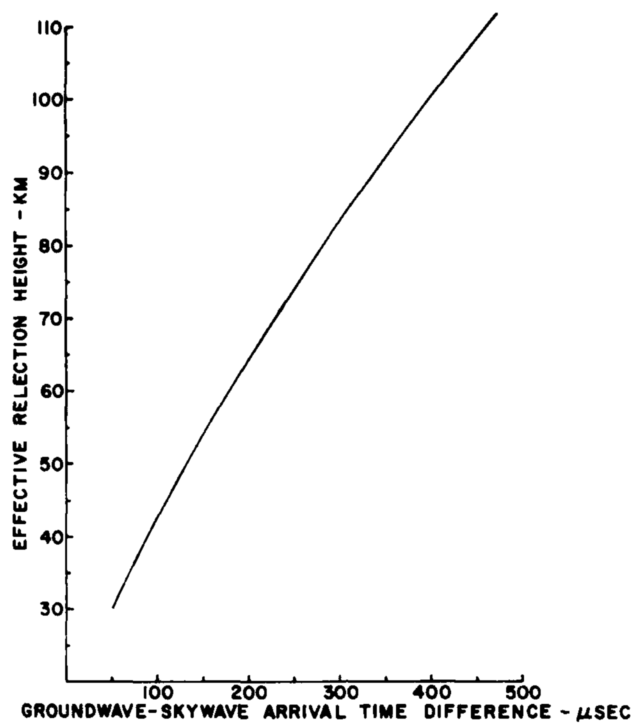

Figure 6. Conversion Curve Groundwave—Skywave Arrival Time Difference to Reflection Height

GMH data presented in this report, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity (10^{-3} mho/m is assumed), with the Wait and Howe[7] corrections applied. Group mirror heights for the parallel and perpendicular waveforms are plotted as a function of frequency in Parts H and I of Figures 8 through 23 for both normal and disturbed conditions. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz. In Figures 8 through 23, Parts L and O, parallel and perpendicular reflection height information is given based on two-hour averaged data for the two-week period; Parts V and W show the 24-hour period of the event onset in greater detail, based on 5-min averaged data. These parts

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7. Wait, J.R., and Howe, H.H. (1956) Amplitude and Phase Curves for Groundwave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat'l Bureau of Standards, U.S. Circ. No. 574.

include a normal reflection height curve for reference purposes. Each point of the reference height curve is an average, by two-hour time blocks, for the 14-day normal period indicated.

2.2.2 REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GHM, we obtained plane wave reflection coefficients[7] by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account the wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient ${}_{\|}R_{\|}$, obtained from analysis of the parallel skywave component, is plotted as a function of frequency for both normal and disturbed conditions in Part H. From the corresponding perpendicular skywave pulses, the coefficient ${}_{\|}R_{\perp}$ was obtained; it appears as a function of frequency in Part I. The ${}_{\|}R_{\|}$ coefficient for 16 kHz is plotted as a function of time-of-day in Part M along with the averaged normal coefficient. As with the reflection heights, a more detailed ${}_{\|}R_{\|}$ coefficient plot, based on 5-min averaged data is shown in Part V. To show the variation in reflectivity as a function of frequency during the event, the reflection coefficients were calculated at 8 kHz, 16 kHz, and 22 kHz and are plotted in Part N as a function of time for the 14-day period. The corresponding reflection coefficient plots for ${}_{\|}R_{\perp}$ are given in Parts P, Q, and W.

For certain coefficient data points, plotted as asterisks, the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained since the skywaves were too weak to provide reliable group delay information. The reflection coefficients were estimated, therefore, using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in Parts M, N, P and Q, but the assumed heights are not used in the GMH averages.

2.3 Polarization Ellipses for the Down-Coming Skywaves

As described by Rasmussen et al,[8] the polarization ellipse of the skywave can be determined from the amplitudes of the parallel and perpendicular components and their phase difference. Each ellipse represents the locus of the tip of the rotation field vector as seen when looking in the direction of propagation of the down-coming skywave, and x-axes being horizontal. The ellipses are drawn to a scale in which the incident wave amplitude is unity, and each division on the axis is 0.1. The direction of rotation is indicated by an arrow. Parts J and K of

8. Rasmussen, J.E., et al (1975) Low Frequency Wave-Reflection Properties of the Equatorial Ionosphere, AFCRL-TR-75-0615, AD A025111.

Figures 8 through 23 present polarization ellipse data as a function of frequency at 5 kHz intervals based on the selected disturbed and normal waveforms of Parts F and G, respectively.

3. SUPPLEMENTARY DATA

In order to interpret the effects of ionospheric disturbances on the VLF/LF ionosounding data, information from several geophysical sensors are included. Parts R and S of Figures 8 through 23 present data from a magnetometer and a 30 MHz riometer operated by RADC at Thule AB, Greenland. The riometer, the conventional monitor of ionospheric disturbances, measures the signal level of cosmic noise passing through the ionosphere. A decrease in the received noise level results from increased absorption caused by enhanced ionization from energetic particles. The riometer data in this report have been normalized to remove the quiet day curve. The data plotted in Part R of each figure give riometer absorption levels. A zero level represents normal undisturbed conditions, a positive deflection shows increased absorption while a negative deflection results from a noise increase as would be associated with a solar radio burst. The effects of energetic particle events are seen as an abrupt increase in the absorption level followed by a gradual recovery to normal levels over a period of several days. The magnetometer data plotted are the horizontal (H) component of the polar magnetic field determined by a 3-axis fluxgate magnetometer at Thule AB. The magnetometer responds to the effects of polar ionosphere current systems related to disturbance events.

In addition to the information from the ground-based monitors, particle flux data are presented from the Applied Physics Laboratory of Johns Hopkins University experiments aboard the IMP 7 and 8 satellites.* These satellites are in roughly circular orbits at about 35 earth radii. The data presented in Parts T and U are hourly averages of differential flux levels for protons in two energy ranges: 0.97 to 1.85 MeV and 13.7 to 25.2 MeV. These particle data are most important for relating the VLF/LF ionosounder effects to the size of a particular disturbance.

*Particle data obtained from the National Space Science Data Center, Greenbelt, Maryland.

4. DISTURBANCE CHARACTERISTICS

Table 1 gives a summary of the data presented for each event covered in this report. In addition, data are included for 6 events which occurred from 1974-1977. These events were described in a previous report.[9]

Table 1. Solar Particle Events

Event Date	Figure/ Point No.	Maximum 13.7-25.2 MeV Proton Flux No./cm^2 sec sr MeV	Minimum 16 kHz H Reflection Height km	30 MHz Riometer Absorption dB	Illumination Conditions
13 Feb (044)	8	60.0	56	6.0	day-night
25 Feb (056)	9	0.05	64	<0.5	day-night
7 Mar (066)	10	0.02	70	<0.5	day-night
8 Apr (098)	11	0.1	65	<0.5	day-night
11 Apr (101)	12	3.0	58	3.0	daytime
17 Apr (107)	13	0.2	60	0.5	daytime
28 Apr (118)	14	no data	no data	9.8	daytime
7 May (127)	15	10.0	57	1.0	daytime
11 May (131)	16	0.1	63	<0.5	daytime
31 May (151)	17	0.4	63	1.0	daytime
11 July (192)	18	0.3	64	1.0	daytime
8 Sept (251)	19	0.18	63	<0.5	day-night
23 Sept (266)	20	100.0	51	10.0	day-night
8 Oct (281)	21	0.8	65	<0.5	day-night
10 Nov (314)	22	0.3	65	1.0	day-night
12 Dec (345)	23	0.1	74	<0.5	nighttime
		1974-1977 Events[9]			
	Point No.				
5 Nov 74 (309)	24	1.3	63	<0.5	day-night
30 Apr 76 (121)	25	6.0	58	3.0	daytime
22 Aug 76 (235)	26	0.6	60	1.7	daytime
26 Jul 77 (207	27	0.02	70	<0.5	daytime
24 Sept 77 (267)	28	2.0	57	2.0	day-night
22 Nov 77 (326)	29	14.0	64	0.75	nighttime

9. Turtle, J.P., Rasmussen, J.E., Klemetti, W.I. (1980) Effects of Energetic Particle Events on VLF/LF Propagation Parameters, 1974-1977, RADC TR-80-307.

1978 was a very active year; ionospheric disturbance effects of 16 energetic particle events are given in this report. The characteristics of the effects of energetic particles on the VLF/LF propagation parameters are a function of event size and solar illumination conditions. The reflection heights for both parallel and perpendicular components drop coincident with the influx of energetic particles. The level to which the height drops depends upon the magnitude of the particle flux and the solar illumination conditions during the event.

Data giving 16 kHz ‖ reflection heights and particle flux levels from Table 1 are plotted in Figure 7. The maximum of the 13-25 MeV particle flux is plotted as a function of the lowest reflection height during the event. A "best fit" straight line drawn through the points indicates a roughly exponential relationship between the particle flux and the resulting reflection height. Two points, 23 and 29, are separated from the rest and were not used in calculating the "best fit" line.

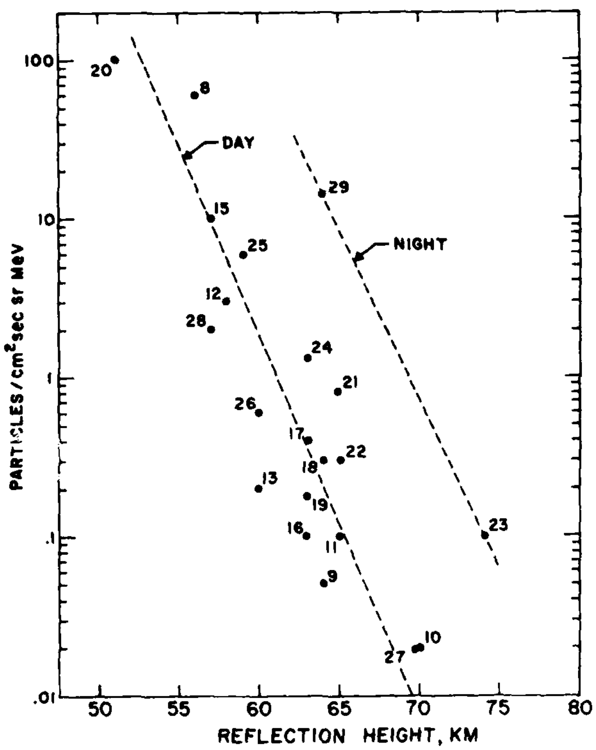


Figure 7. 13.7 - 25.2 MeV Proton Flux vs the Minimum 16 kHz ‖ Reflection Height

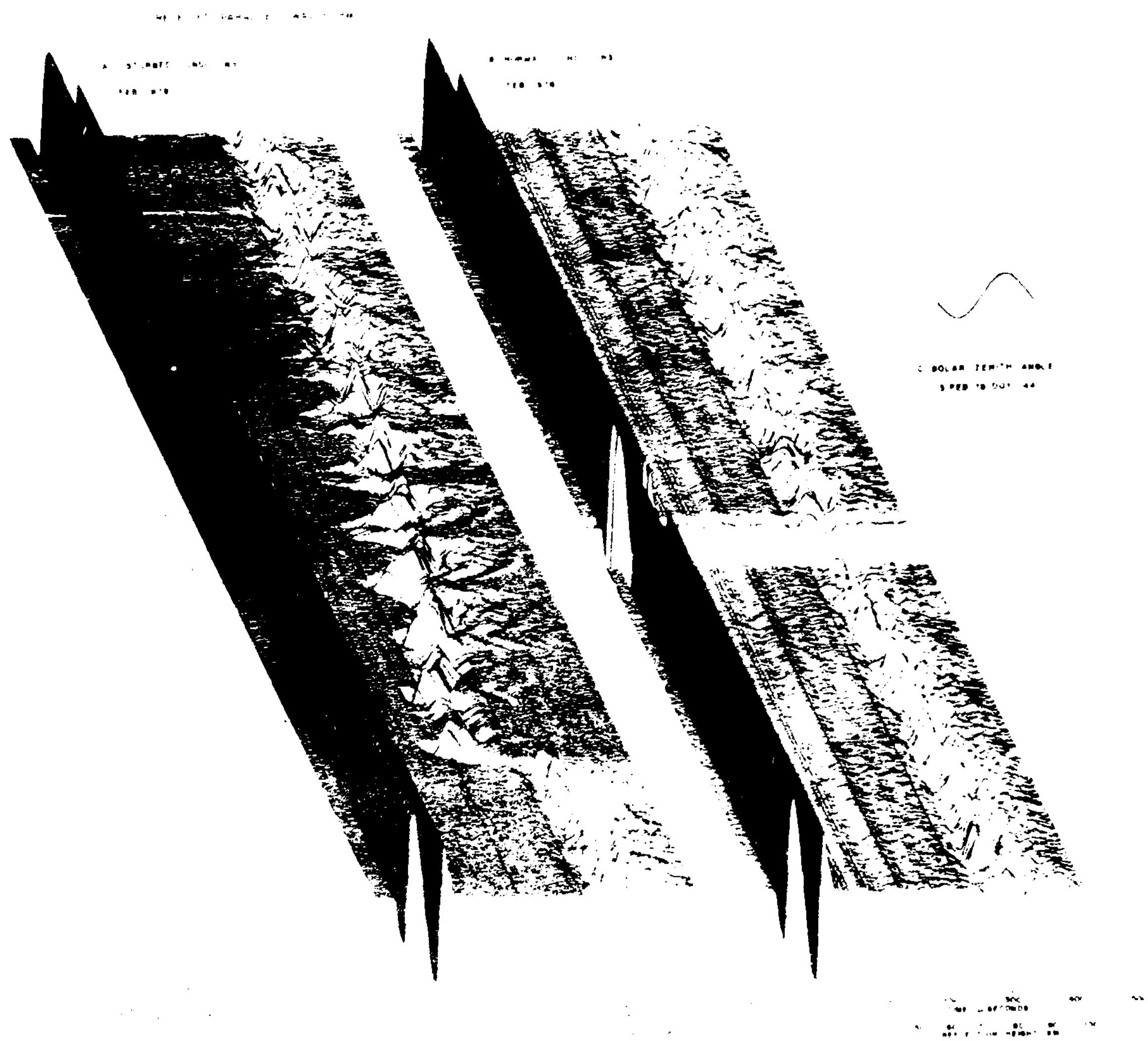
These were both nighttime events and suggest the probability of two curves, one for sunlit events and the other for events where there is no solar illumination. During event recovery various patterns are seen in the data depending on the solar illumination. There is no diurnal height variation during continuous daytime (Figure 18) or continuous nighttime (Figure 23) events. However, a diurnal height variation is seen during day-night events resulting from changing solar illumination conditions (Figure 20).

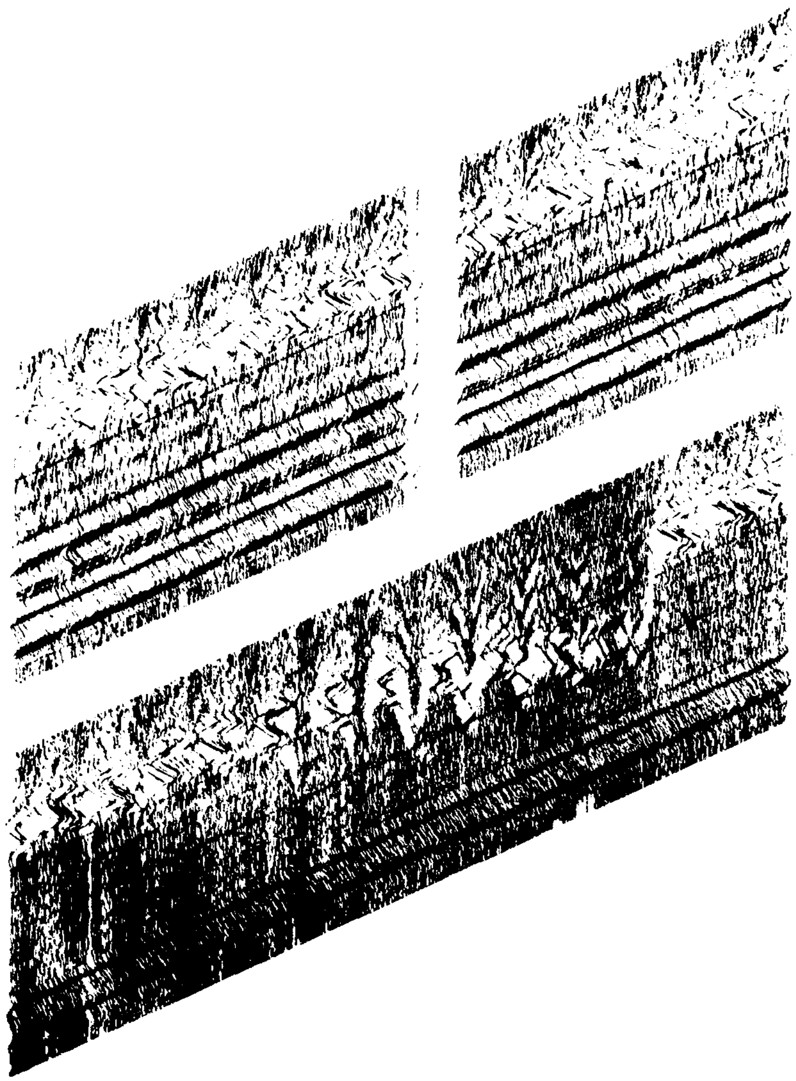
A more complex behavior is shown by the VLF/LF reflection coefficients during energetic particle events. During daytime events the reflection coefficients can show an increase with respect to normal conditions. There is less diurnal variation during disturbed daytime conditions than during normal conditions, the effects of particle ionization appear to override the effects of varying solar zenith angle. During the recovery the reflection coefficients gradually drop and go through a null. A typical daytime disturbance is seen in Figure 15. Reflection coefficients during nighttime events show effects similar to the reflection heights; a drop followed by a gradual recovery. During day-night events the interaction between varying solar ionization with particle ionization produce a more complex disturbance pattern.

13 February 1978 Solar Particle Event

Date: 13 February	Day: 44
Report Figure: 8	
Related Solar Flare:	0255 UT X-ray class: M7
Start of Ionospheric Disturbance:	1950 UT
Time of Maximum 13-25 MeV Proton Flux:	14 February 0600 UT
Maximum Flux:	60 particles/cm^2 sec sr MeV
Length of Particle Event:	7 days
Lowest 16 kHz Reflection Height:	56 km
30 MHz Riometer Absorption:	6 dB
Solar Zenith Angle Range:	89° - 117°
Illumination Conditions:	Day-Night

This strong event occurred at the transition between nighttime and day-night conditions. The undisturbed (normal) 3-dimensional waveform plots (parts B and E) show that during the period covered by this event there is insufficient solar radiation to cause a diurnal height variation in the reflection parameters. During the first days of the event the depressed 16 kHz H reflection height curves (parts L and O) also showed little diurnal change; however, during the event recovery a diurnal variation is noted. As particle ionization decreased diurnal variations in solar radiation were sufficient to cause a difference in the day and night reflection heights. The nighttime portion of the daily curve recovered more rapidly than the daytime. The reflection coefficient curves (parts N and Q) show a drop in signal strength at event maximum followed by a gradual recovery. A strong diurnal variation appeared suddenly during the latter part of the recovery.


SOLAR ZENITH ANGLE



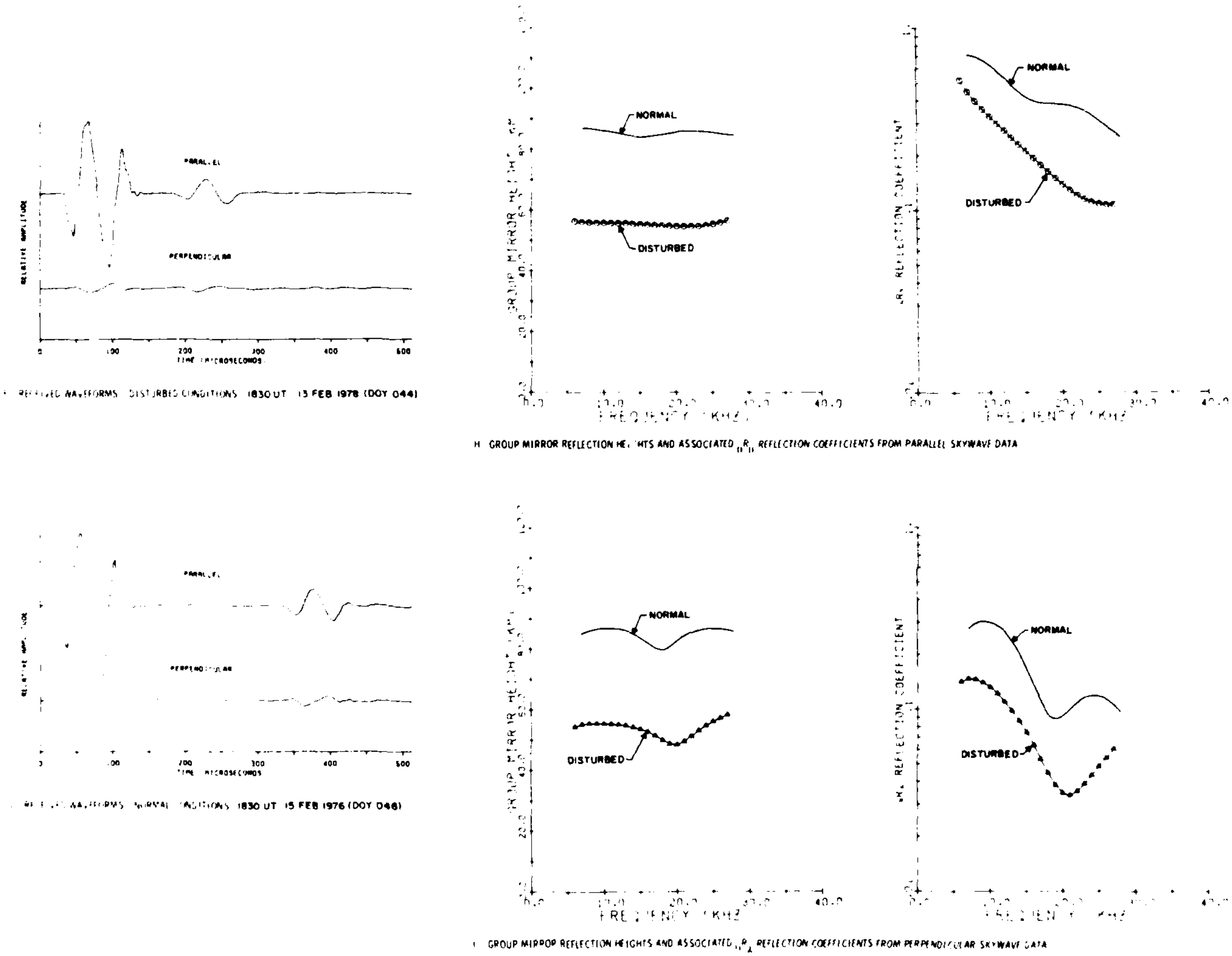
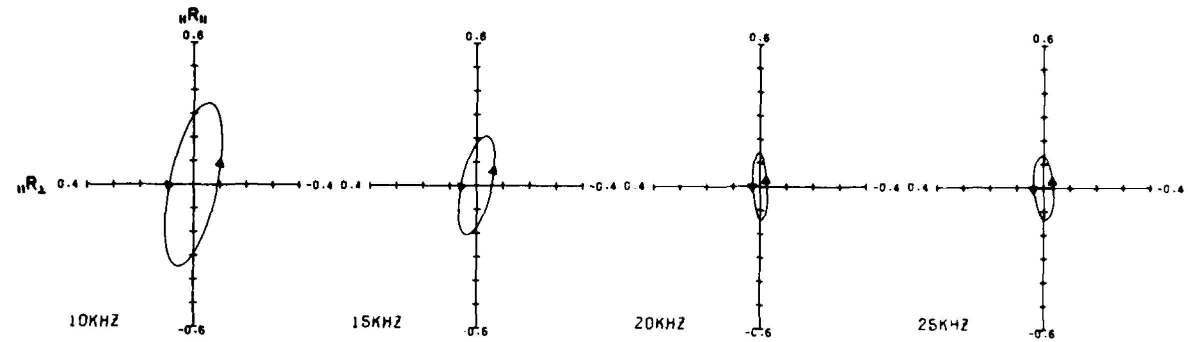
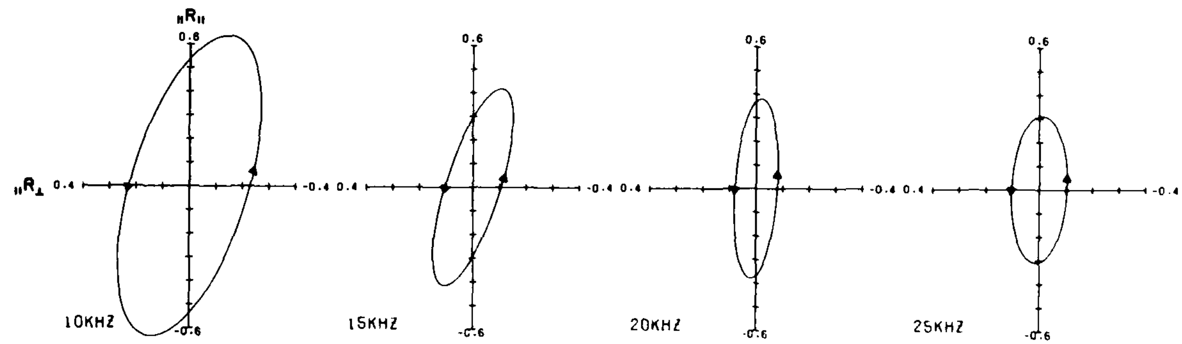


Figure 8. VLF/LF Ionospheric Reflectivity Data for 13 February 1978 (DAY 044) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 8. VLF/LF Ionospheric Reflectivity Data for 13 February 1978 (DAY 044) Solar Particle Event (Cont)

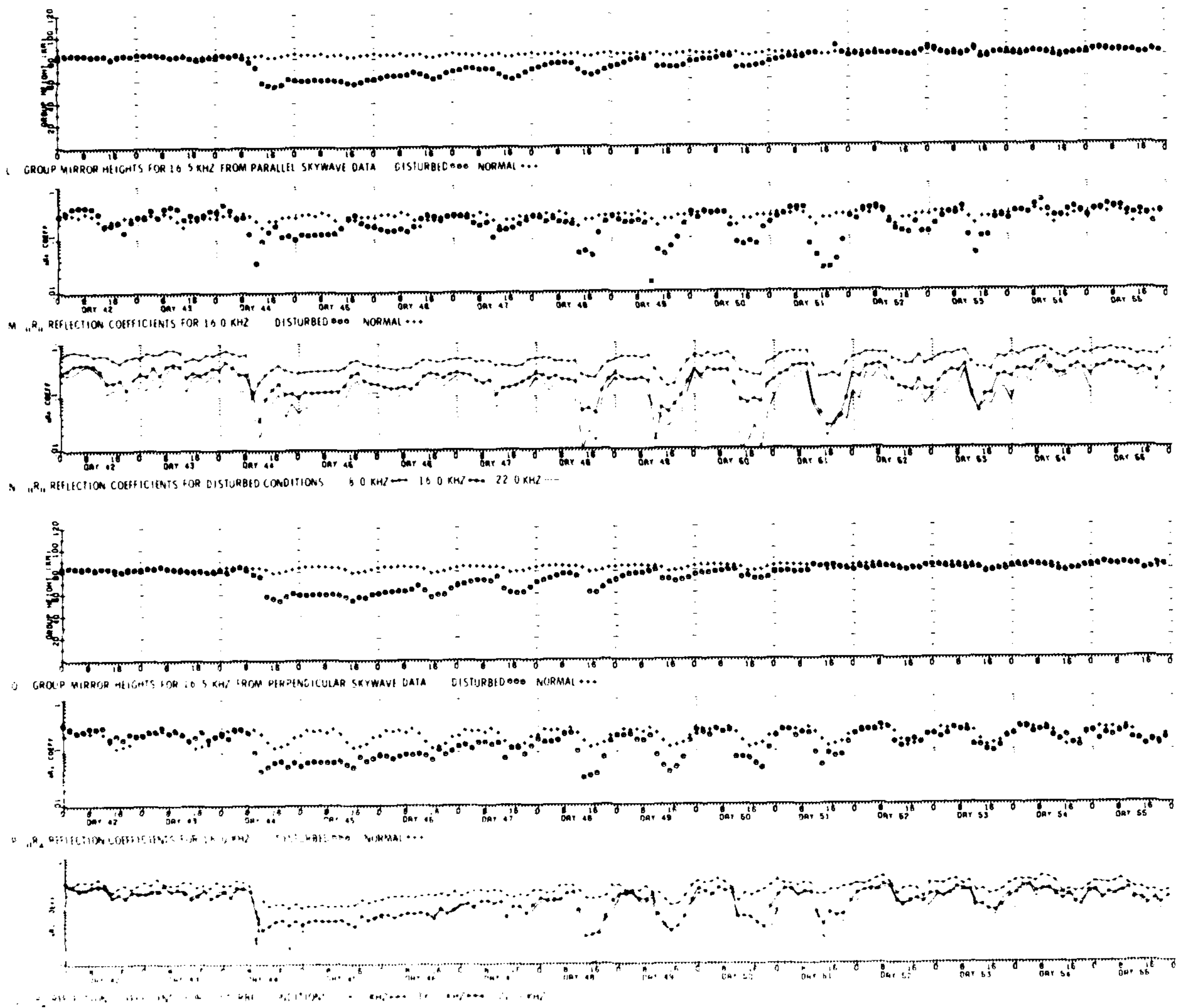


Figure 8. VLF/LF Ionospheric Reflectivity Data for 13 February 1978 (DAY 044) Solar Particle Event (Cont)

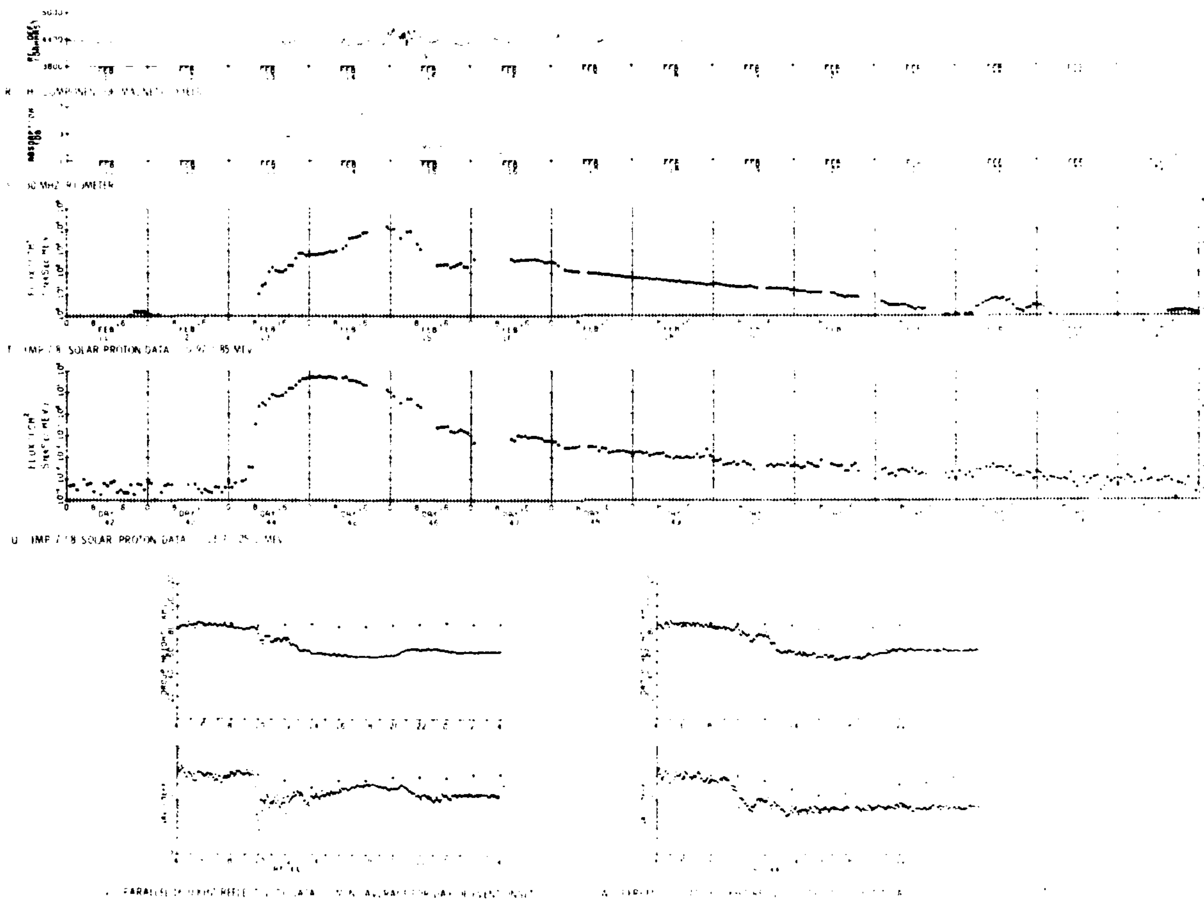
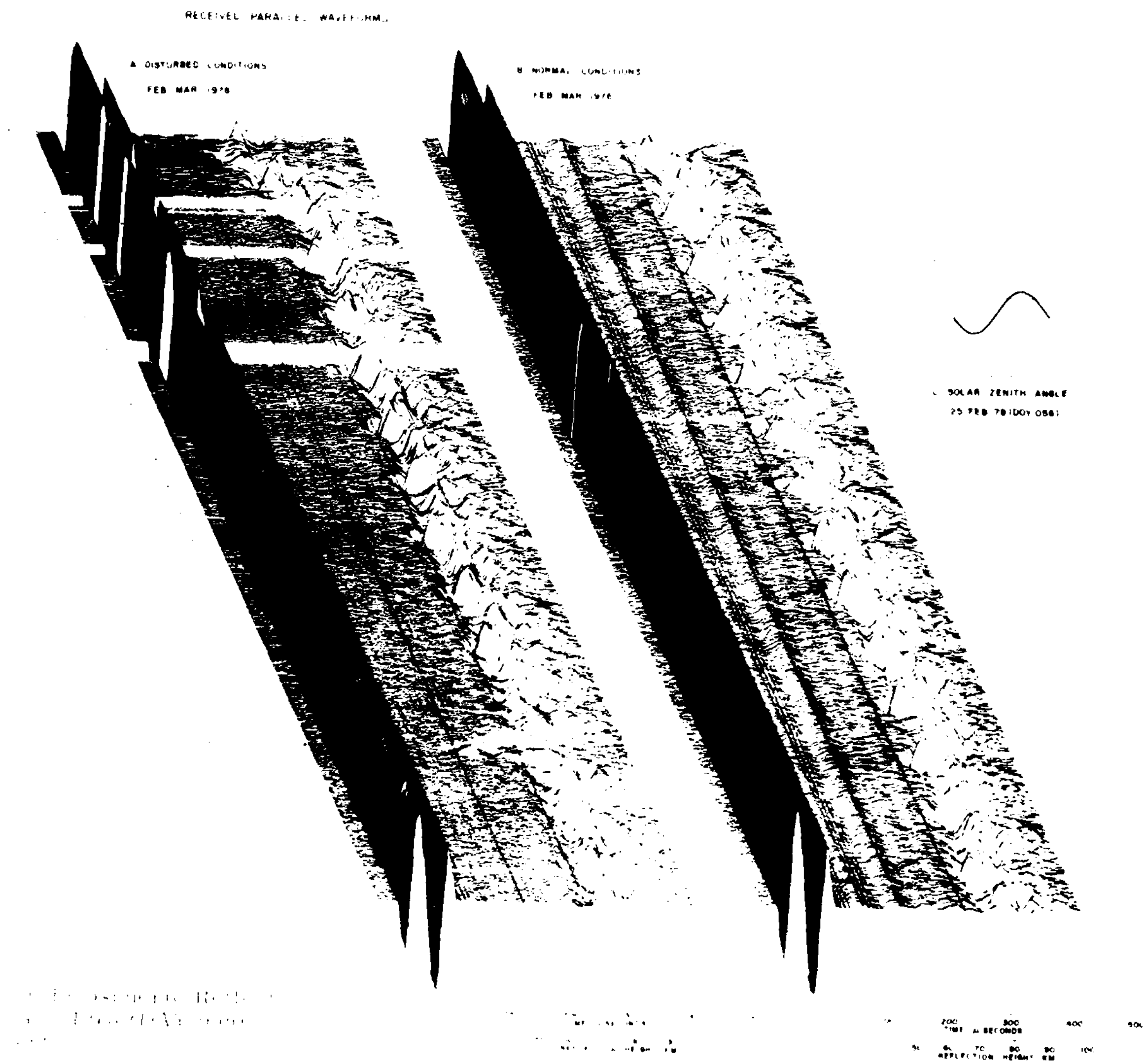


Figure 8. VLF/LF Ionospheric Reflectivity Data for 13 February 1978 (DAY [illegible]) [illegible] (Cont)

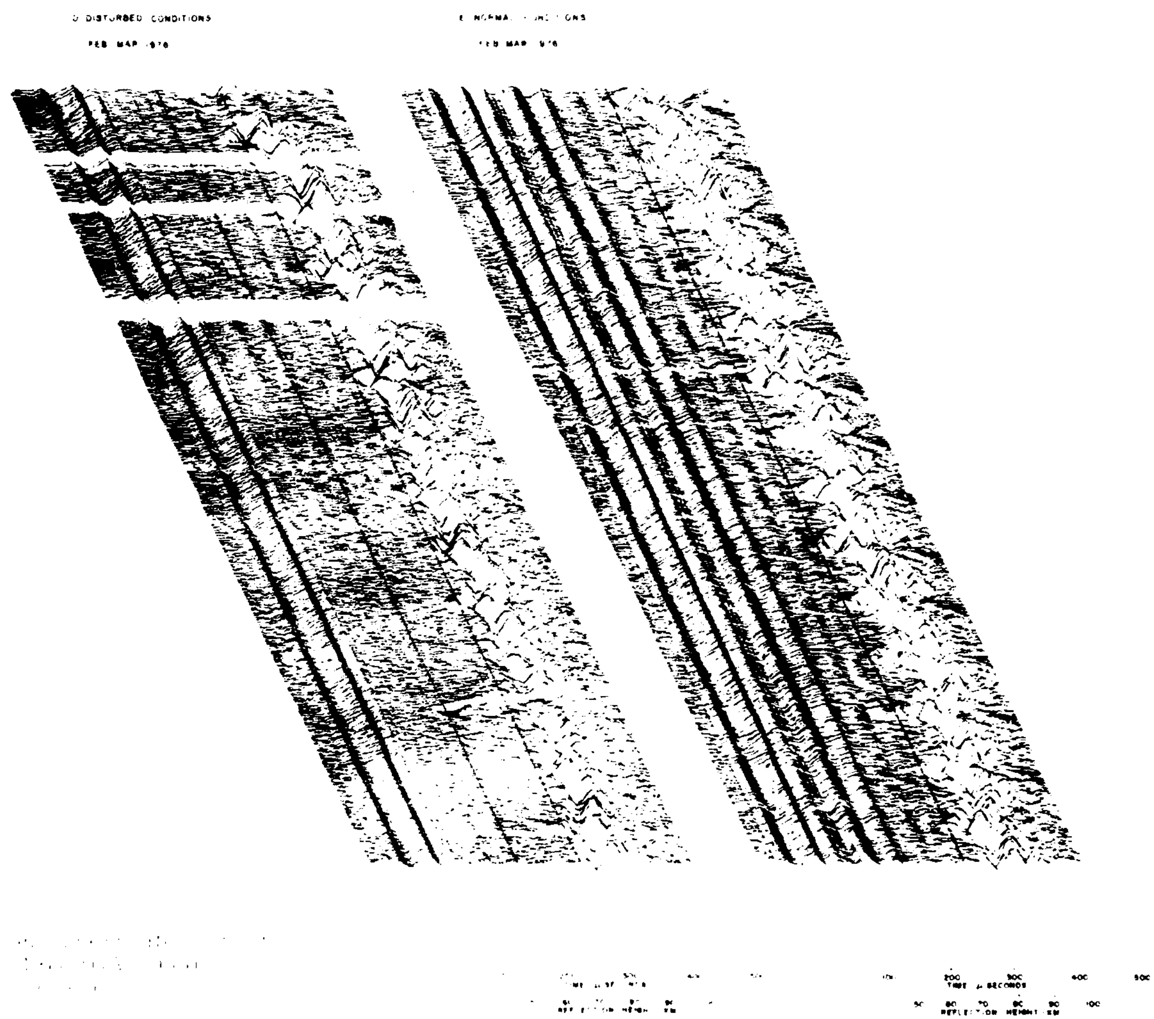
25 February 1978 Solar Particle Event

Date:	25 February	Day: 56	
Report Figure:	9		
Related Solar Flare:		1453 UT	X-ray class: M4
Start of Ionospheric Disturbance:		1555 UT	
Time of Maximum 13-25 MeV Proton Flux:		2000 UT	
Maximum Flux:		0.05 particles/cm^2 sec sr MeV	
Length of Particle Event:		1 day	
Lowest 16 kHz Reflection Height:		64 km	
30 MHz Riometer Absorption:		< 0.5 dB	
Solar Zenith Angle Range:		85° - 113°	
Illumination Conditions:		Day - Night	

This was a short-lived low energy event. The satellite particle data (parts T and U) indicate that the 1.85 MeV low energy protons were first recorded at about 0800 UT, this was eight hours earlier than the 25-MeV protons. According to the 5-min time average ionosounding data (parts V and W), the change in reflection heights and coefficients did not occur until the arrival of the high energy protons at about 1555 UT. The low energy particles did not produce enough ionization to disturb the reflection parameters.


RECEIVED PARALLEL WAVEFORMS
A DISTURBED CONDITIONS
FEB MAR 1978
B NORMAL CONDITIONS
FEB MAR 1978
SOLAR ZENITH ANGLE
25 FEB 78 (DOY 056)
200
300
400
TIME SECONDS
REFLECTION HEIGHT KM

RECEIVED PERPENDICULAR WAVEFORMS



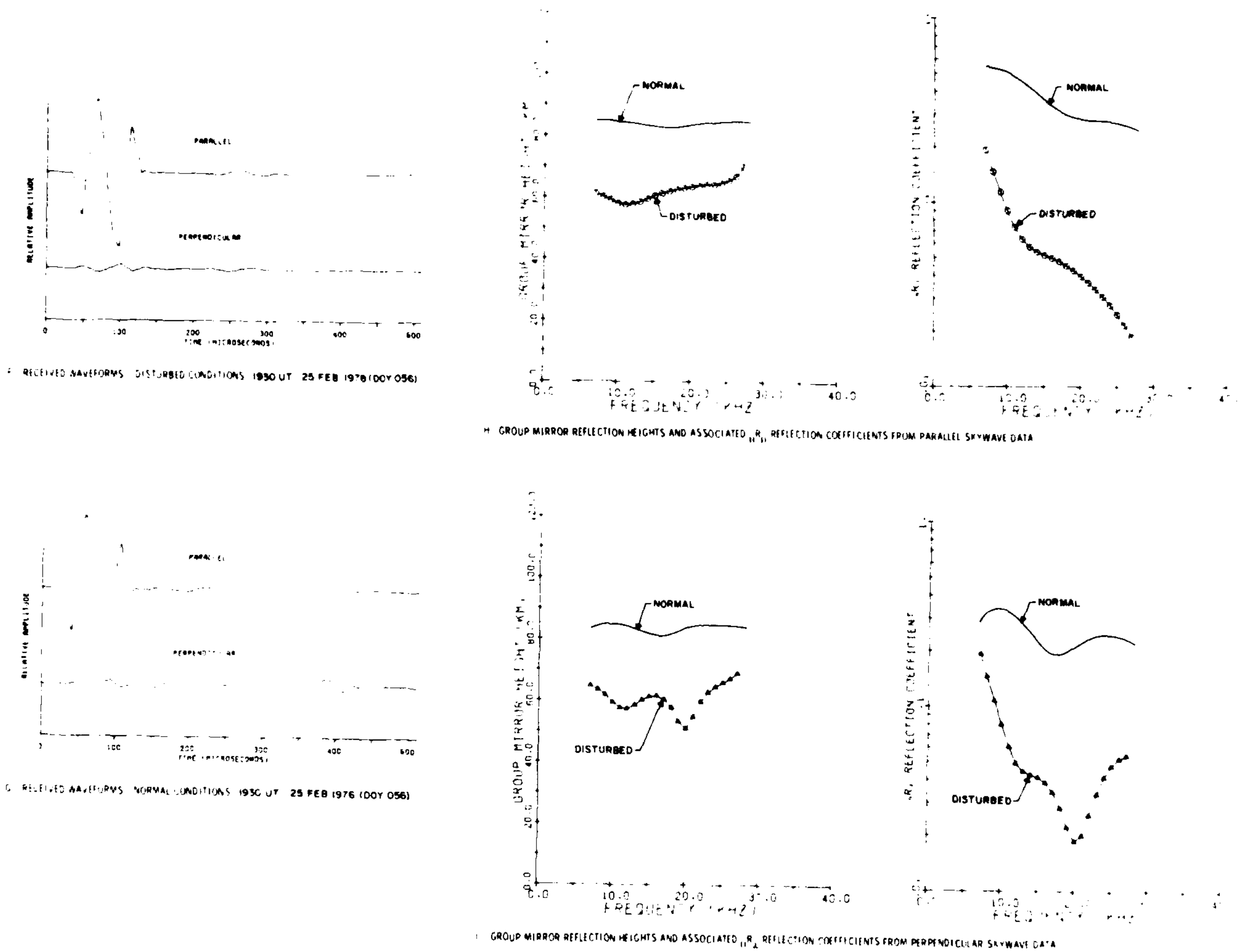
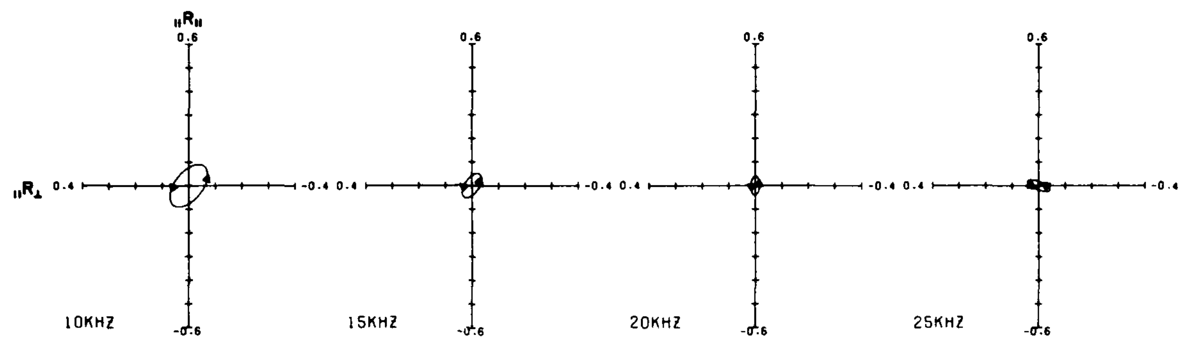
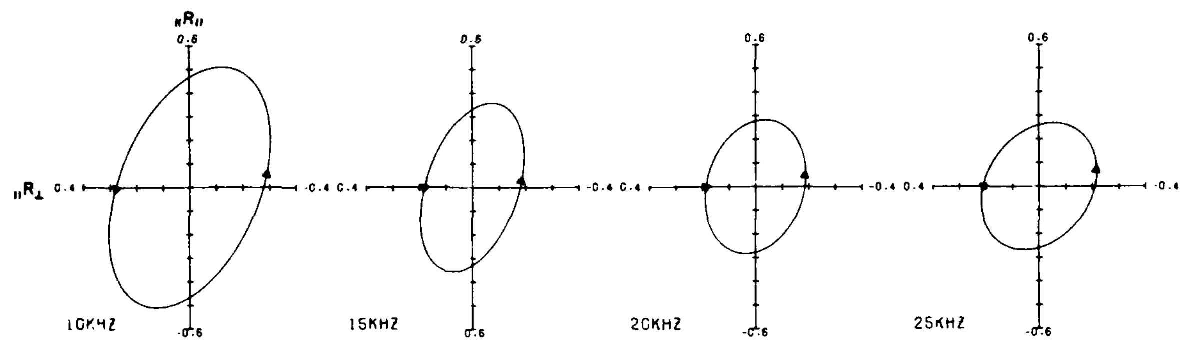


Figure 9. VLF/LF Ionospheric Reflectivity Data for 25 February 1978 (DAY 056) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 9. VLF/LF Ionospheric Reflectivity Data for 25 February 1978 (DAY 056) Solar Particle Event (Cont)

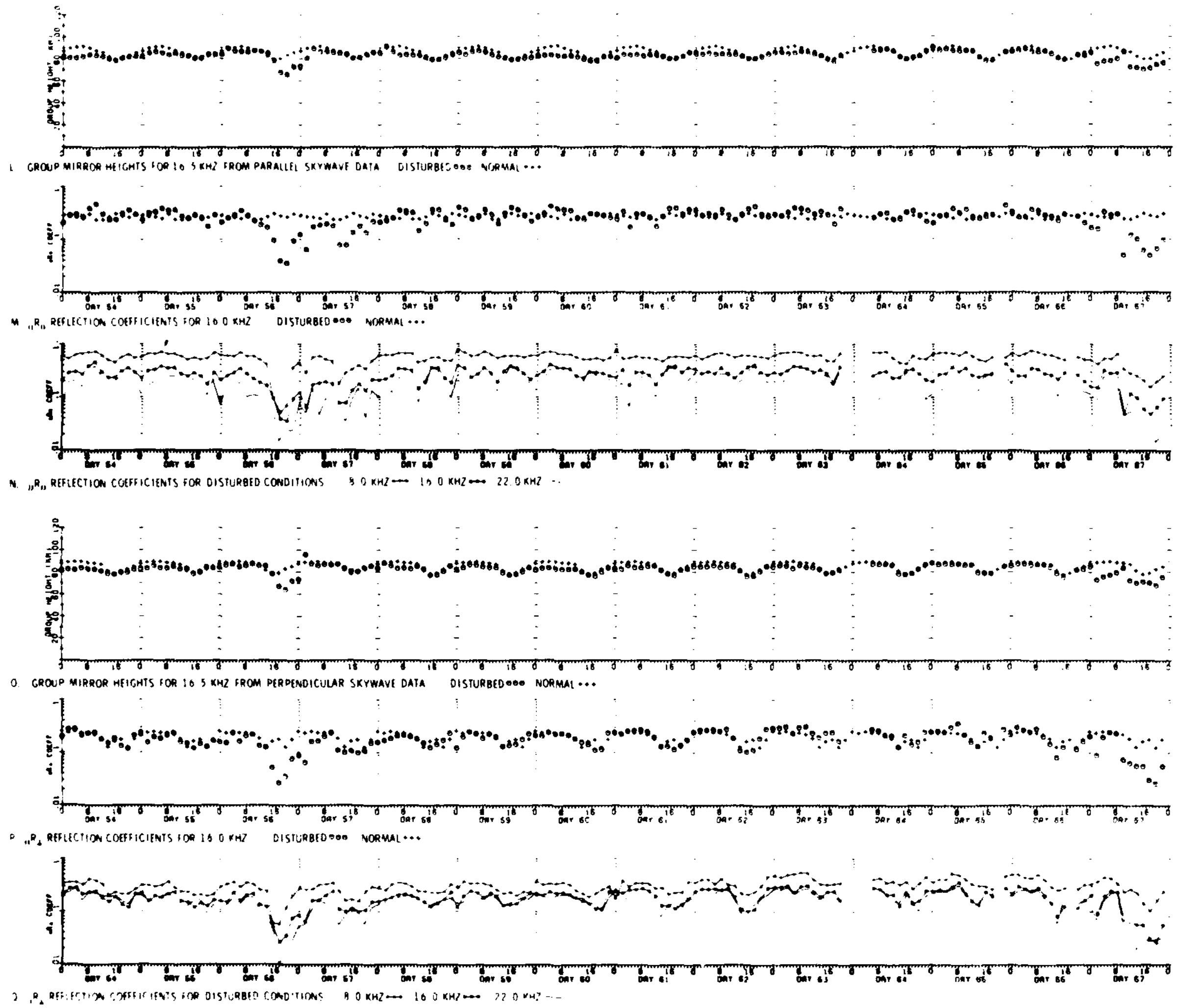


Figure 9. VLF/LF Ionospheric Reflectivity Data for 25 February 1978 (DAY 056) Solar Particle Event (Cont)

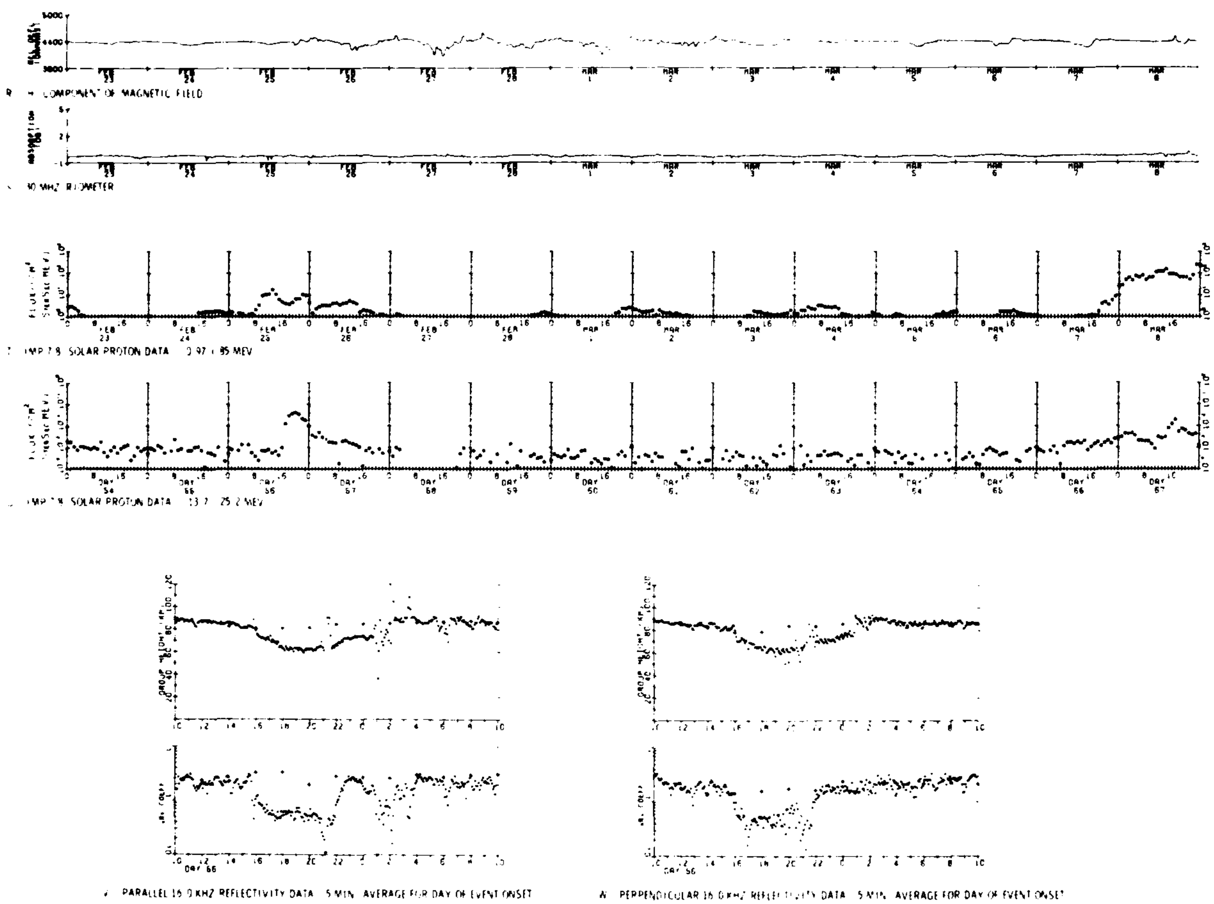


Figure 9. VLF/LF Ionospheric Reflectivity Data for 25 February 1978 (DAY 056) Solar Particle Event (Cont)

7 March 1978 Solar Proton Event

Date: 7 March	Day: 66
Report Figure: 10	
Related Solar Flare:	1213 UT X-ray class: M2
Start of Ionospheric Disturbance:	8 March 0100 UT
Time of Maximum 13-25 MeV Proton Flux:	8 March 1700 UT
Maximum Flux:	0.02 Particles/cm^2 sec sr MeV
Length of Particle Event:	1 day
Lowest 16 kHz Reflection Height:	70 km
30 MHz Riometer Absorption:	< 0.5 dB
Solar Zenith Angle Range:	80° - 180°
Illumination Conditions:	Day - Night

This was the smallest particle event to be covered in this report. The 25 MeV proton flux reached only 0.02 particles/cm^2 sec sr MeV and the 16 kHz H reflection height dropped to 70 km. In spite of the low particle flux the combination of particle ionization and solar radiation were enough to produce lower reflection heights than were recorded during the 12 December 1978 nighttime event which had a five times greater 25 MeV particle flux (see Table 1).

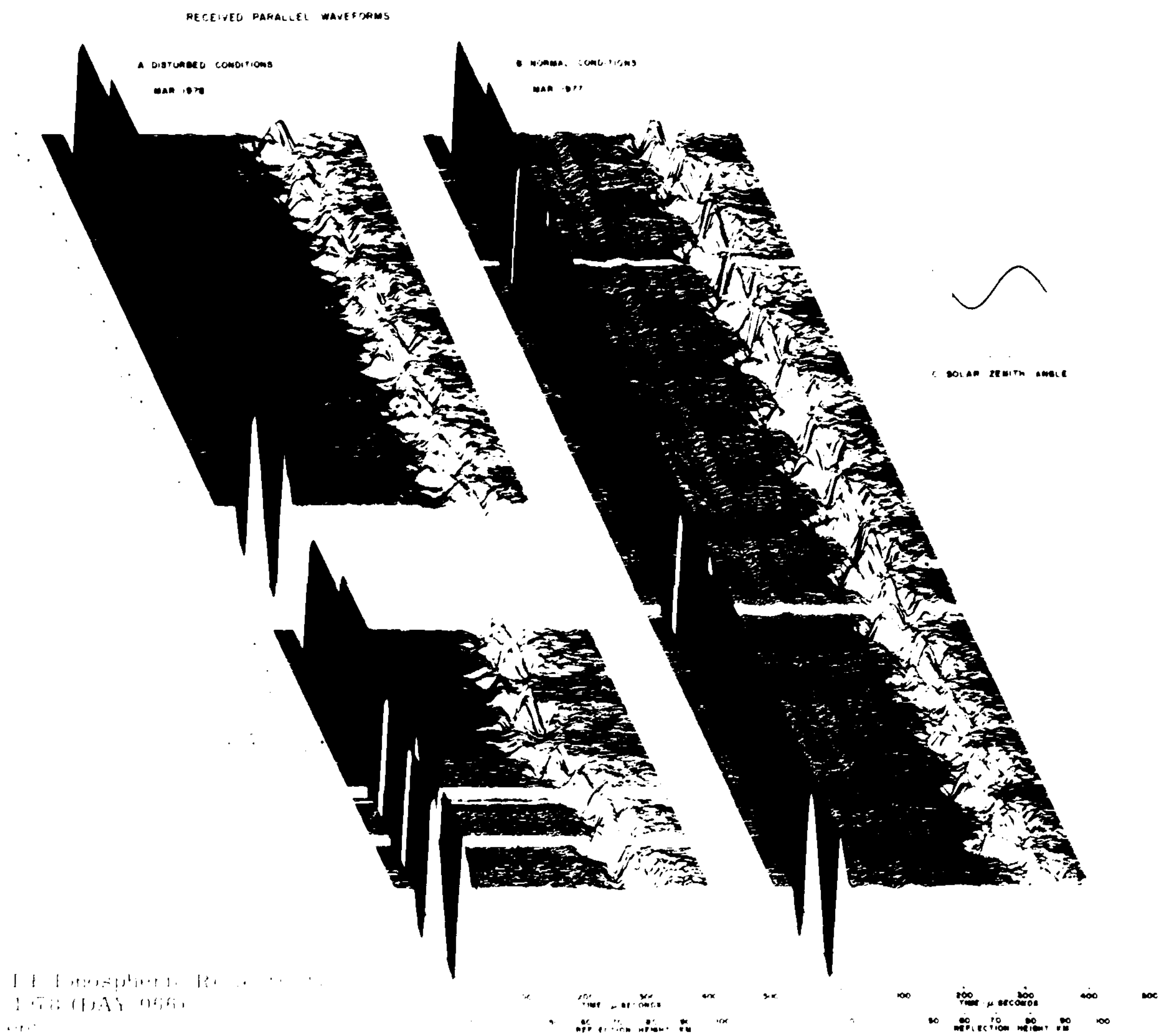


Figure 10. ... ELF ... Ionospheric Re...
... 1978 (DAY 066)
...

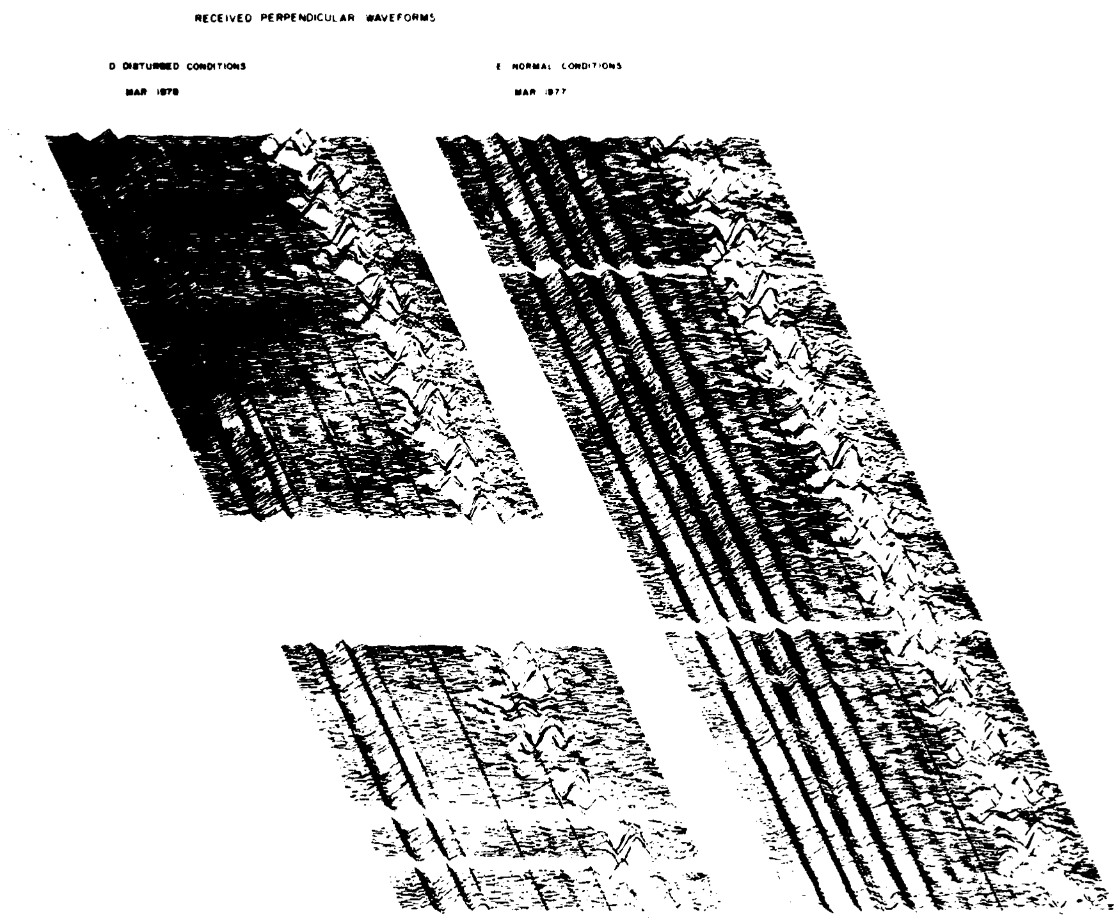
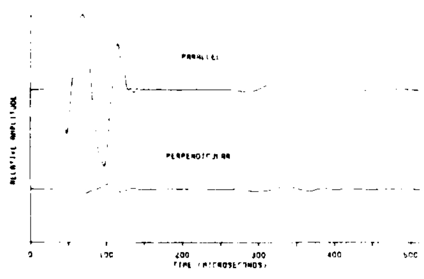
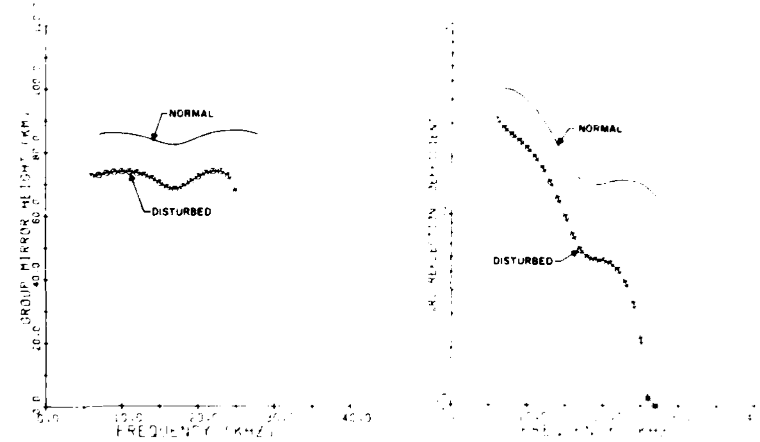


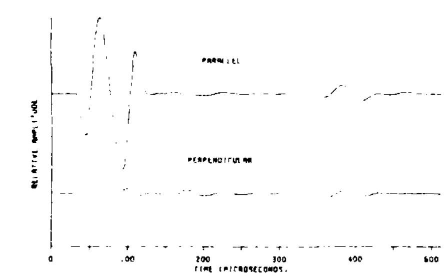
Figure 10. VLF/LF Ionospheric Reflectivity Data for 7 March 1978 (DAY 066) Solar Particle Event (Cont)



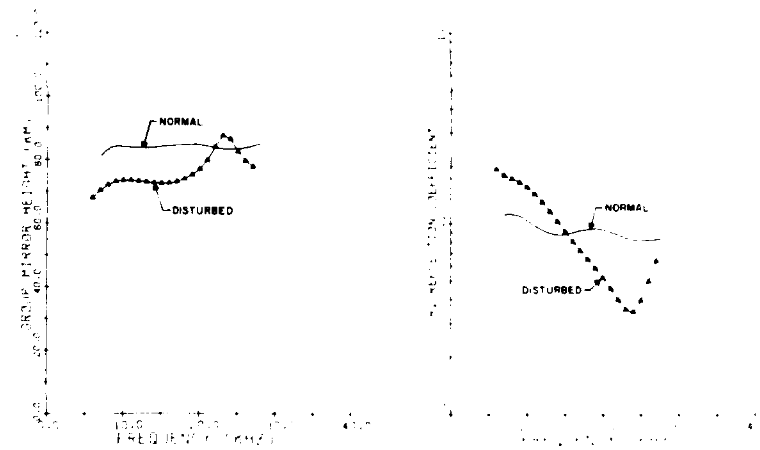
F. RECEIVED WAVEFORMS DISTURBED CONDITIONS 1530 UT 8 MAR 1978 (DOY 067)



H. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA

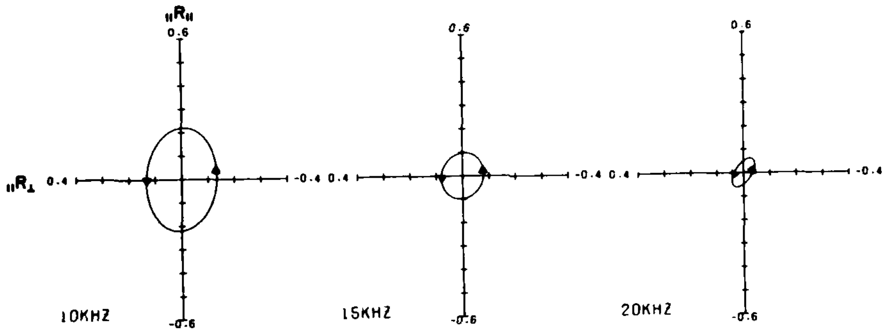


G. RECEIVED WAVEFORMS NORMAL CONDITIONS 1530 UT 8 MAR 1977 (DOY 067)

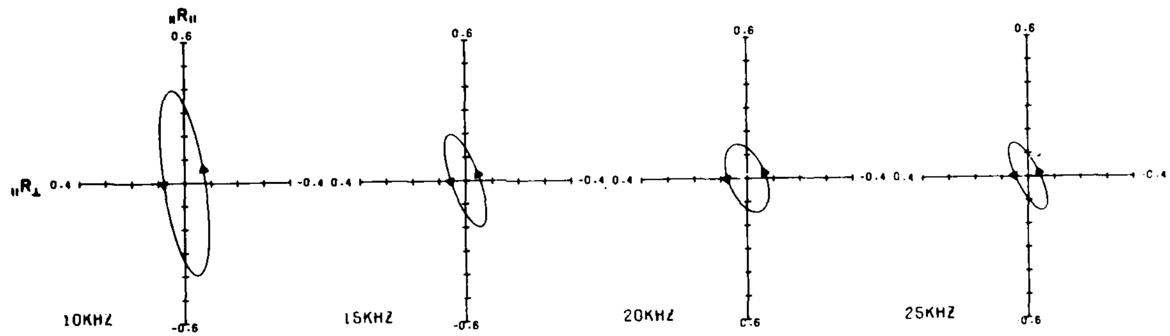


I. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 10. VLF/LF Ionospheric Reflectivity Data for 7 March 1978 (DAY 066) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 10. VLF/LF Ionospheric Reflectivity Data for 7 March 1978 (DAY 066) Solar Particle Event (Cont)

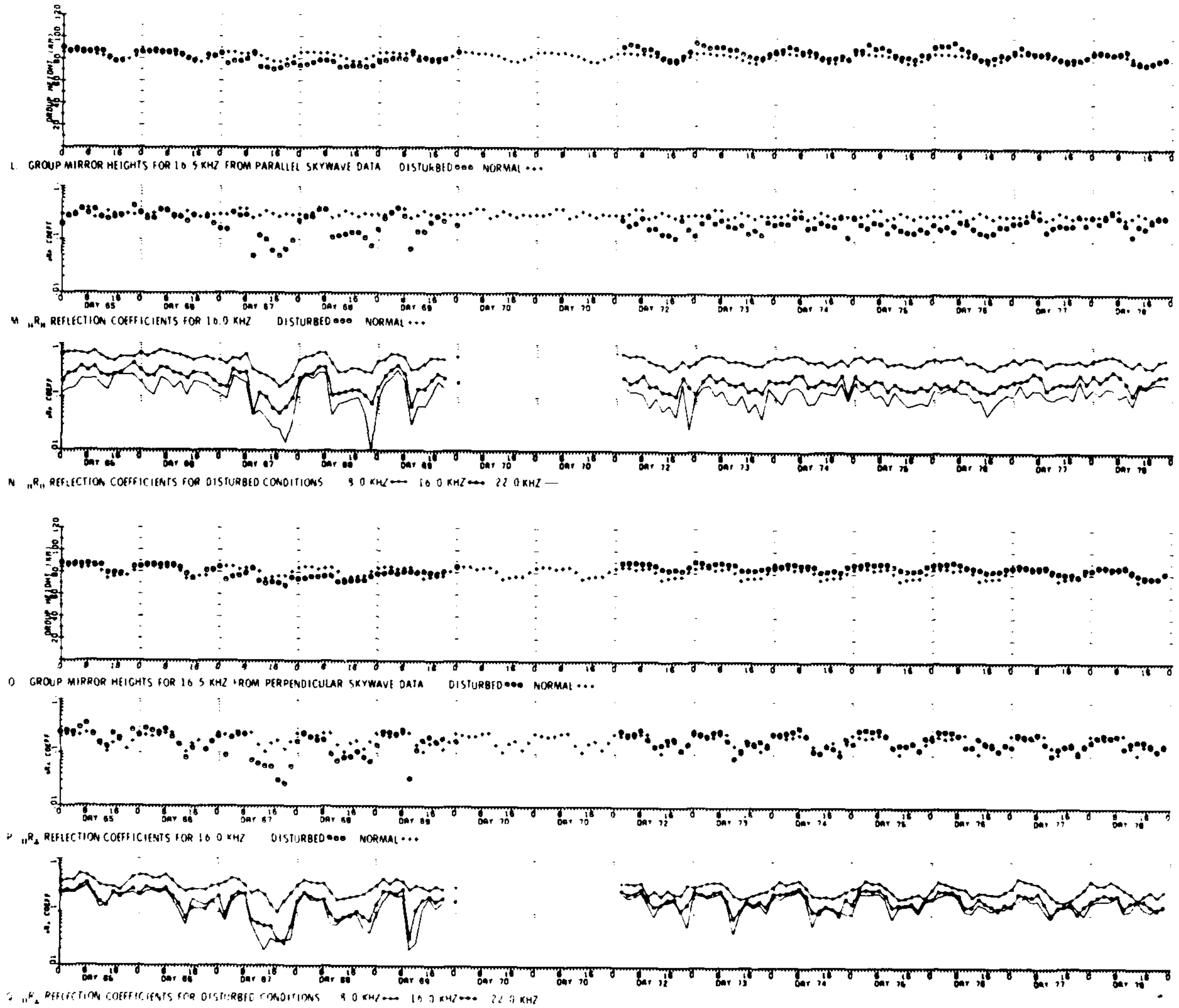


Figure 10. VLF/LF Ionospheric Reflectivity Data for 7 March 1978 (DAY 066) Solar Particle Event (Cont)

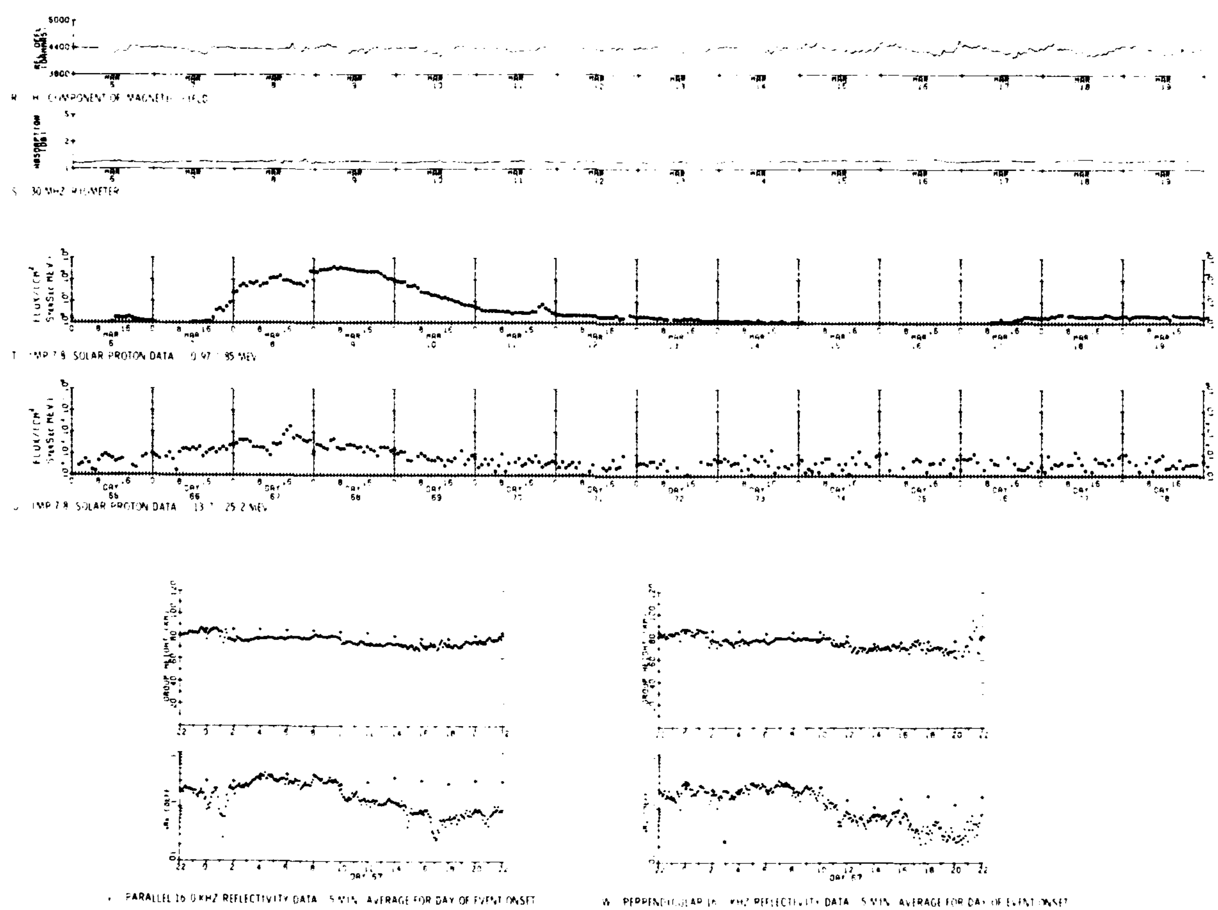
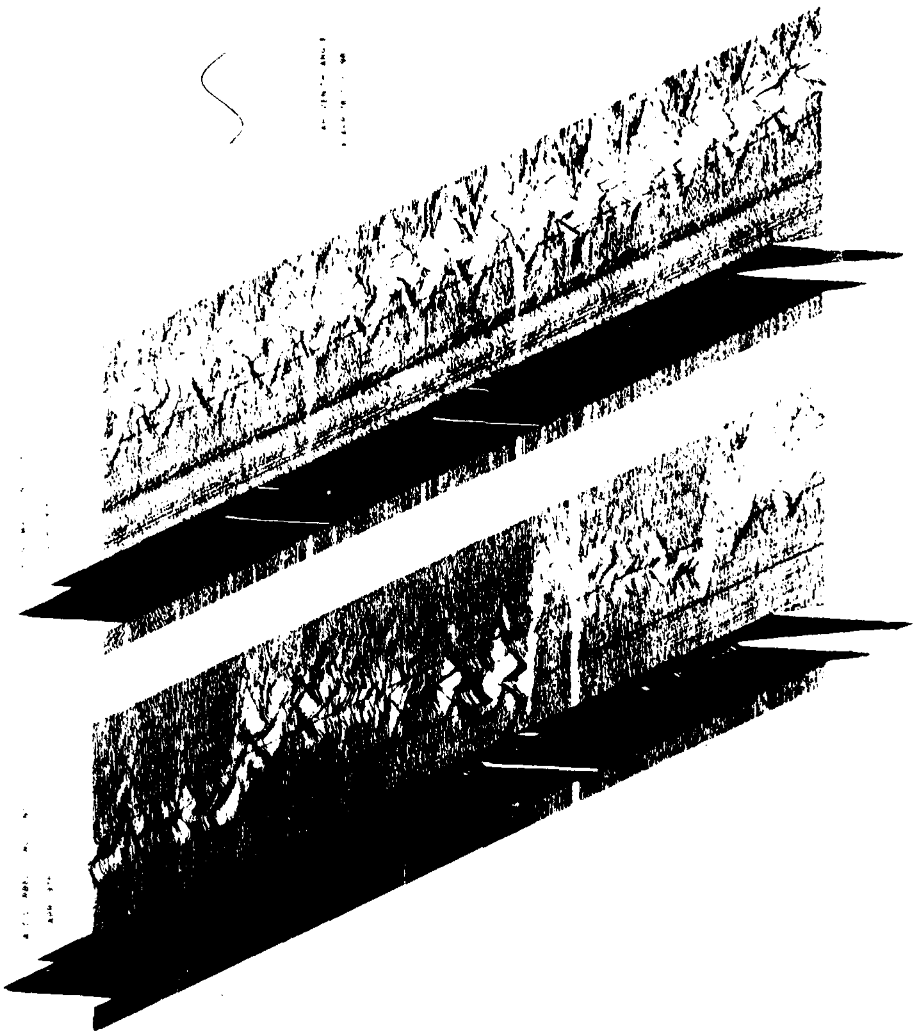


Figure 10. VLF/LF Ionospheric Reflectivity Data for 7 March 1978 (DAY 066) Solar Particle Event (Cont)

8 April 1978 Solar Particle Event

Date: 8 April	Day: 98
Report Figure: 11	
Related Solar Flare:	0201 UT X-ray class: X1
Start of Ionospheric Disturbance:	0300 UT
Time of Maximum 13-25 MeV Proton Flux:	0700 UT
Maximum Flux:	0.1 particles/cm^2 sec sr MeV
Length of Particle Event:	3 days
Lowest 16 kHz Reflection Height:	65 km
30 MHz Riometer Absorption:	< 0.5 dB
Solar Zenith Angle Range:	68° - 96°
Illumination Conditions:	Day-Night

This was the first in a series of eight energetic particle events which occurred during the period from 8 April (DAY 098) through 13 May (DAY 133) Figures 11 through 16 give the data for each separate event. Some of the events occurred only a couple of days apart so that the recovery effects of one event overlapped with the onset of another. The 25 MeV proton flux, seen in part U of Figures 11 through 16, remained above the disturbance threshold (0.01 particles/cm^2 sec sr MeV) for the entire period from 17 April (DAY 107) to 12 May (DAY 132). Both reflection heights and coefficients were continuously disturbed during the period.



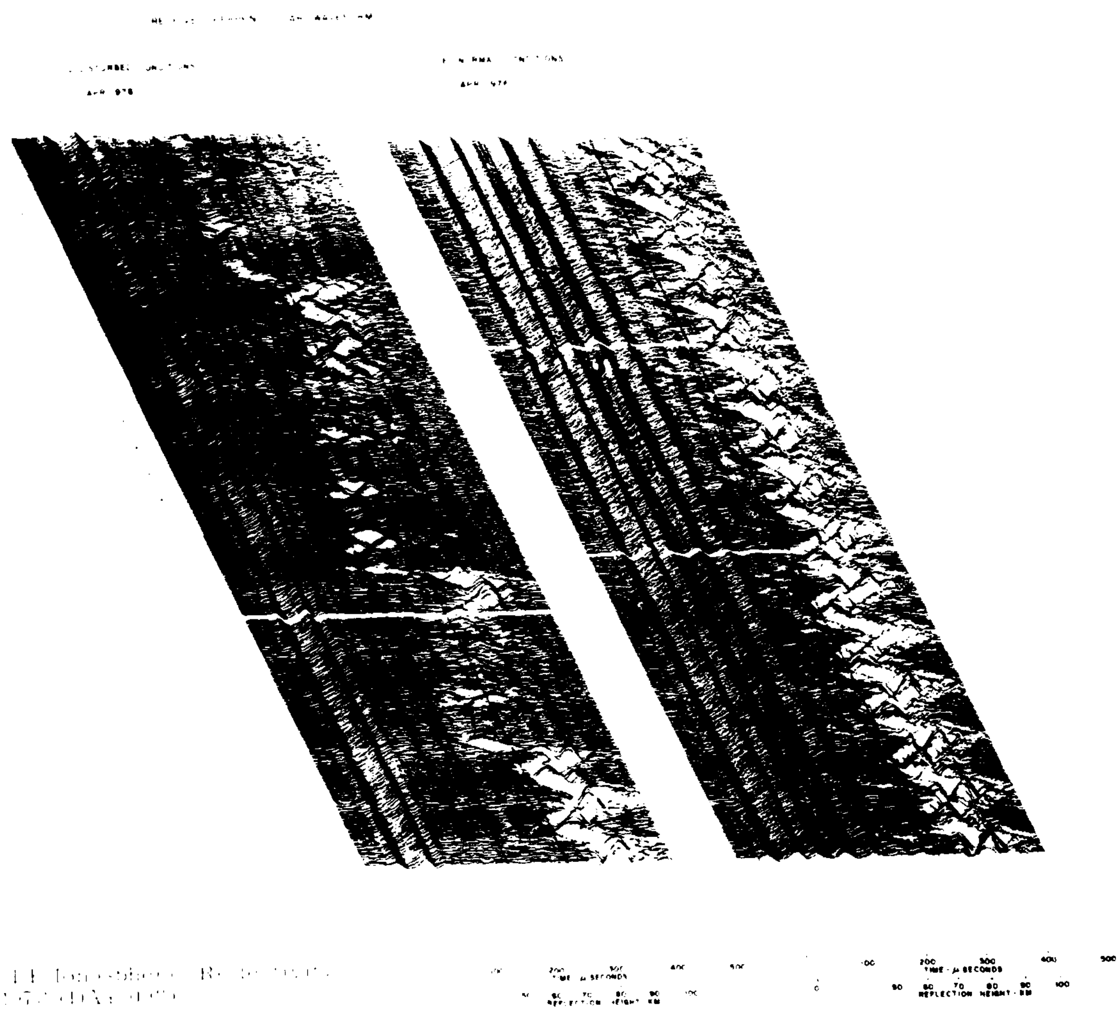

100 200 300 400 500
TIME - μ SECONDS
50 60 70 80 90 100
REFLECTION HEIGHT - KM

Figure 11. [illegible]

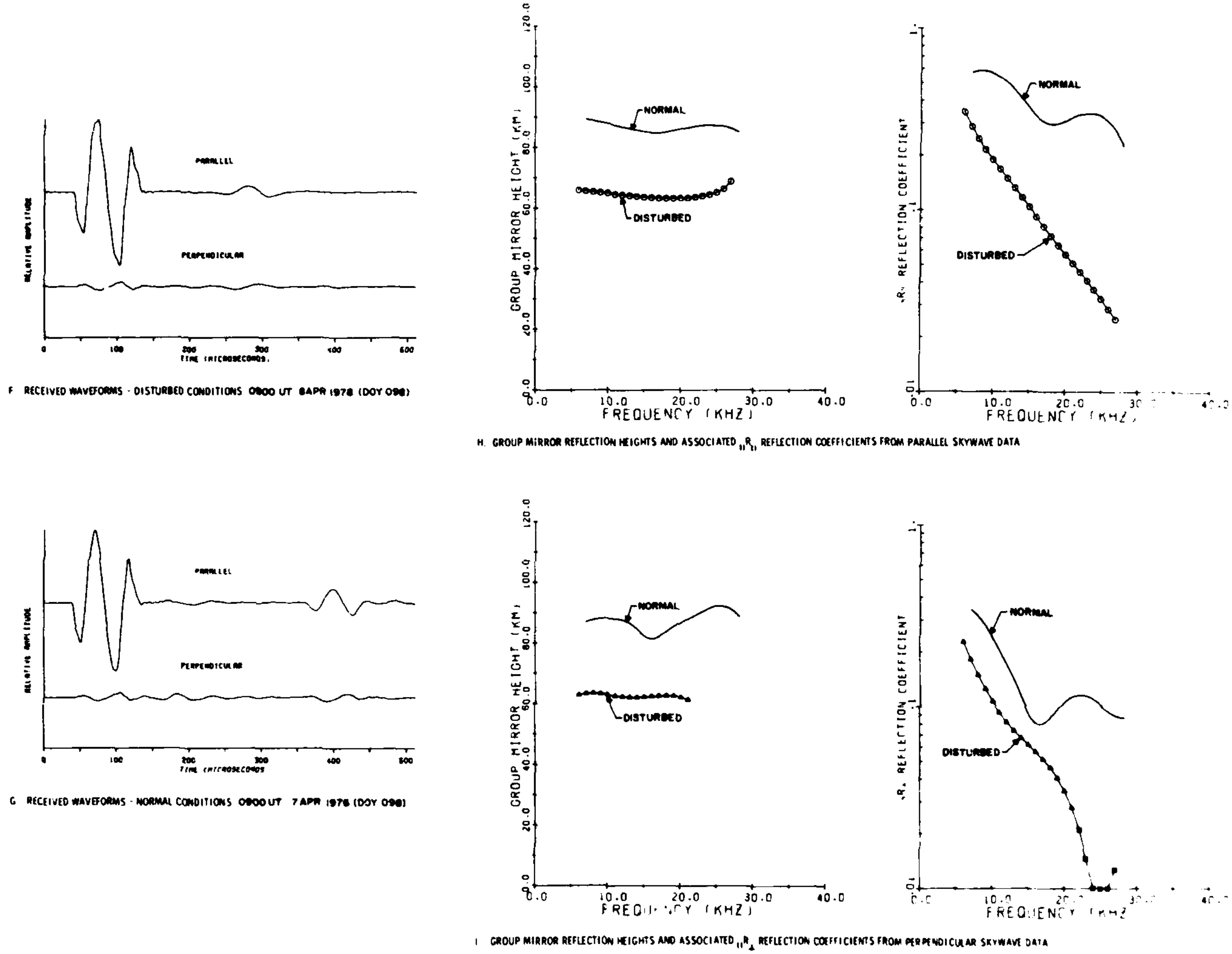
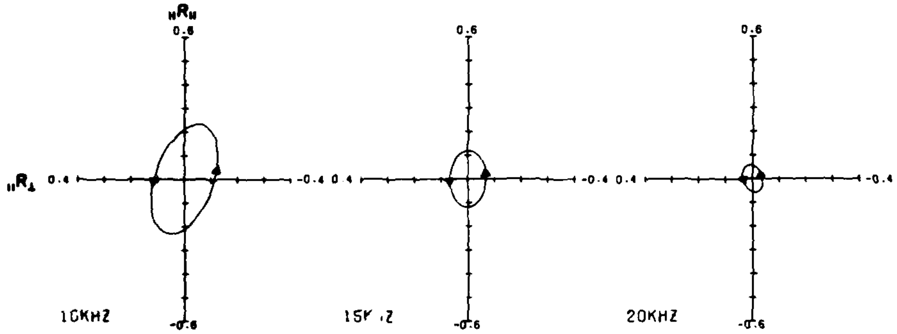
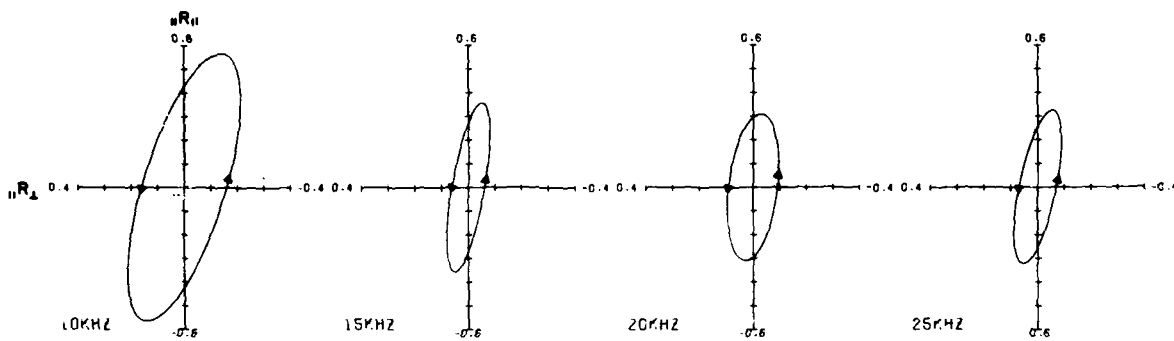


Figure 11. VLF/LF Ionospheric Reflectivity Data for 8 April 1978 (DAY 098) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 11. VLF/LF Ionospheric Reflectivity Data for 8 April 1978 (DAY 098) Solar Particle Event (Cont)

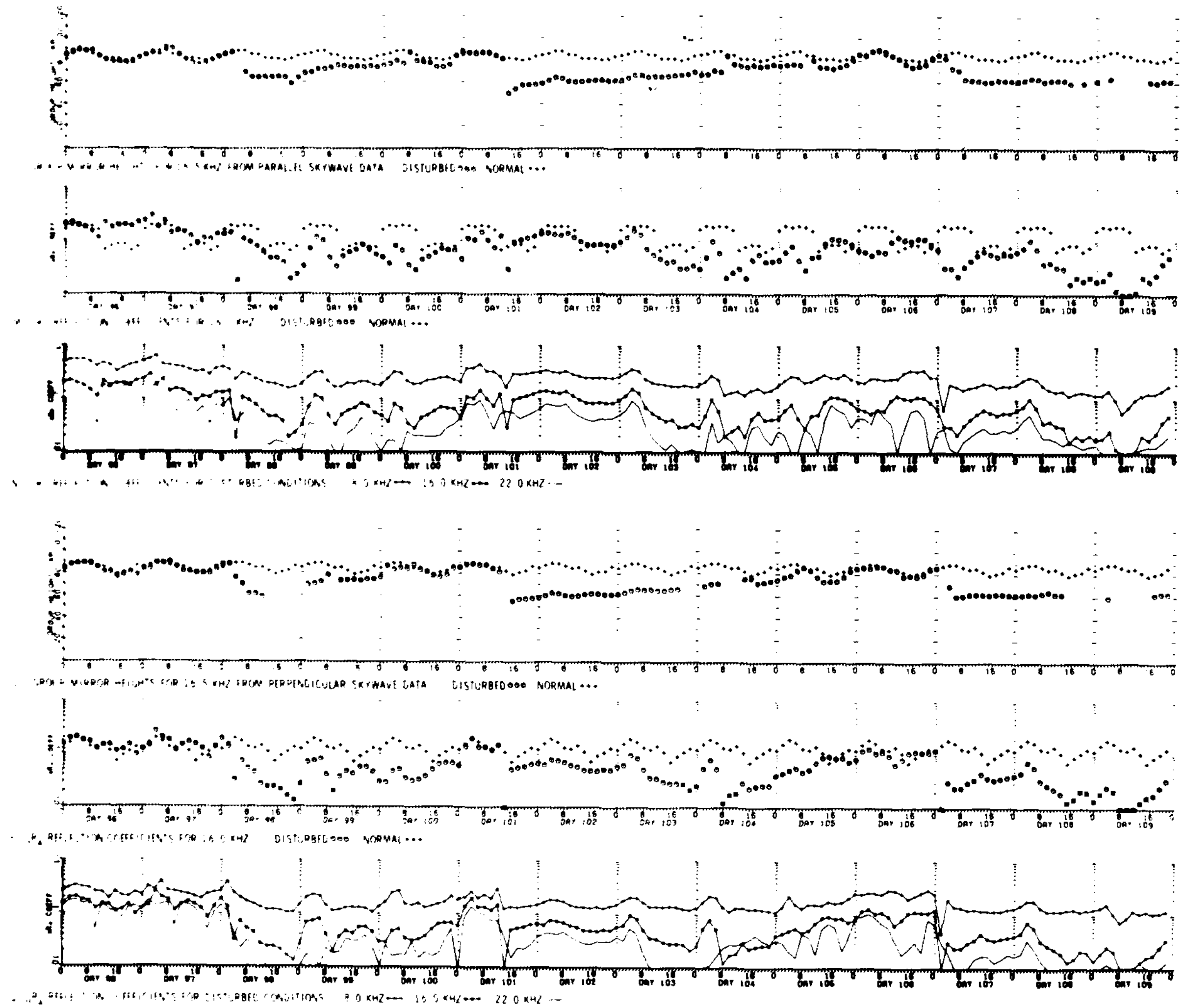


Figure 11. VLF/LF Ionospheric Reflectivity Data for 8 April 1978 (DAY 098) Solar Particle Event (Cont)

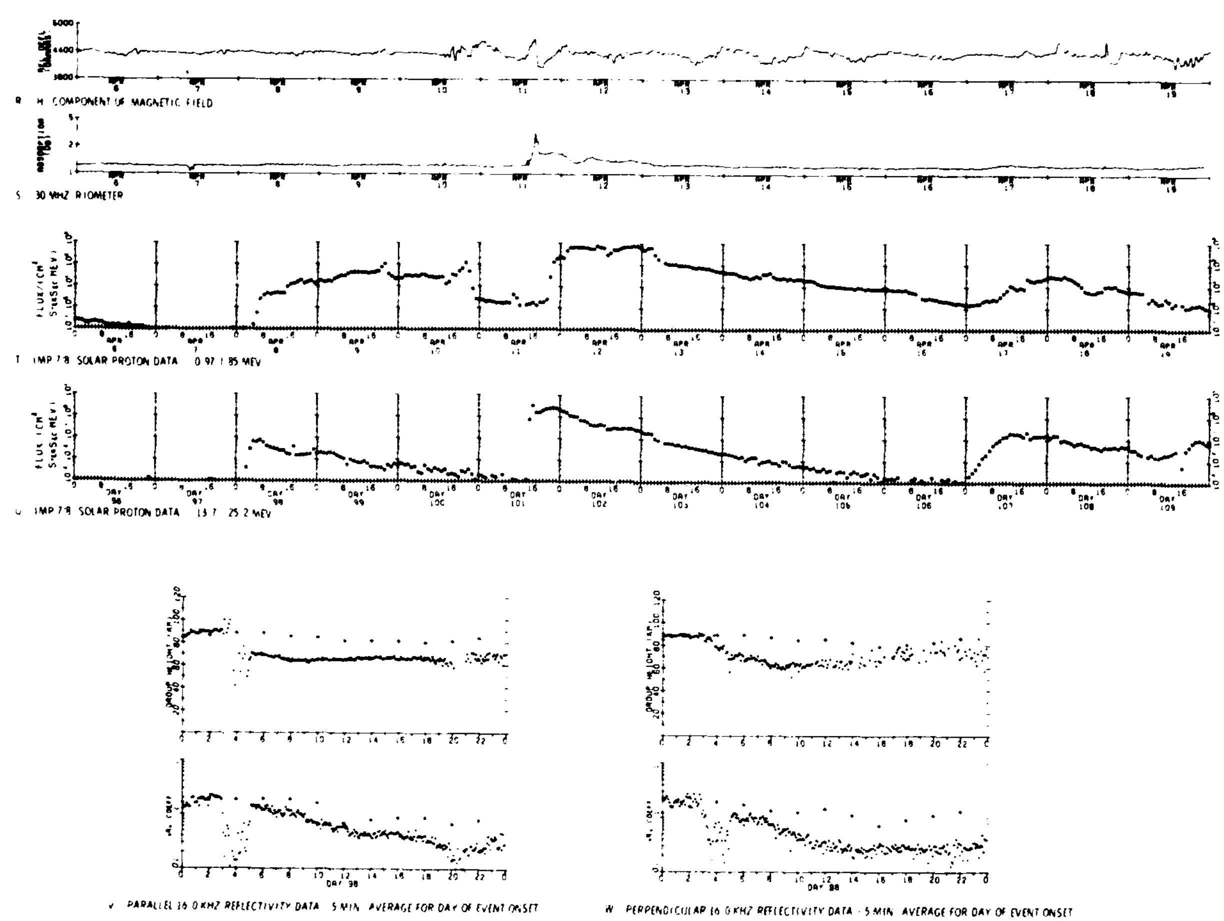


Figure 11. VLF/LF Ionospheric Reflectivity Data for 8 April 1978 (DAY 098) Solar Particle Event (Cont)

11 April 1978 Solar Particle Event

Date:	11 April	Day:	101
Report Figure:	12		
Related Solar Flare:		1340 UT	X-ray class: X2
Start of Ionospheric Disturbance:		1355 UT	
Time of Maximum 13-25 MeV Proton Flux:		2200 UT	
Maximum Flux:		3 particles/cm^2 sec sr MeV	
Length of Particle Event:		4 days	
Lowest 16 kHz Reflection Height:		58 km	
30 MHz Riometer Absorption:		3 dB	
Solar Zenith Angle Range:		67° - 95°	
Illumination Conditions:		Daytime	

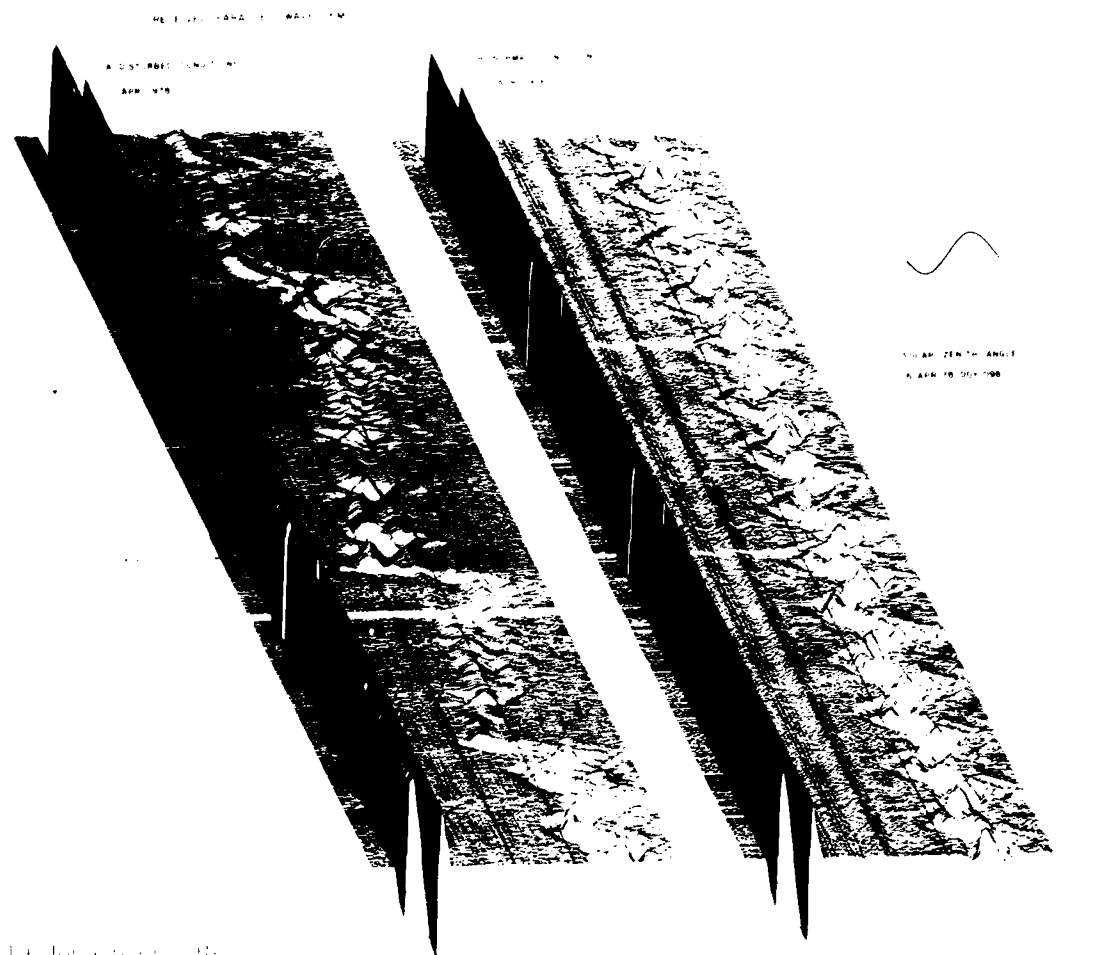
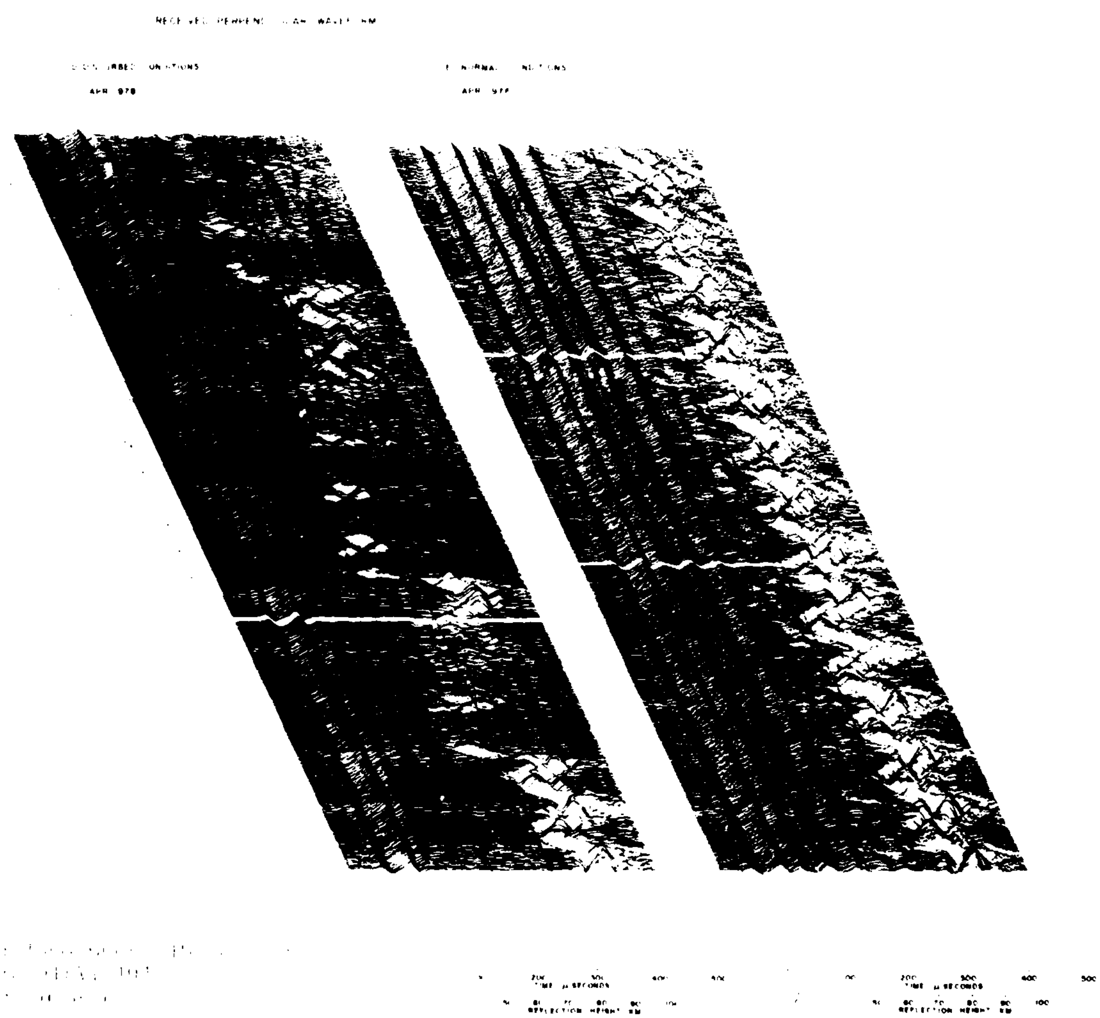


Figure 12. [illegible] 11 April 1979 [illegible]
[illegible]


200 300 400 500
TIME μ SECONDS
REFLECTION HEIGHT KM
200 300 400 500
TIME μ SECONDS
REFLECTION HEIGHT KM

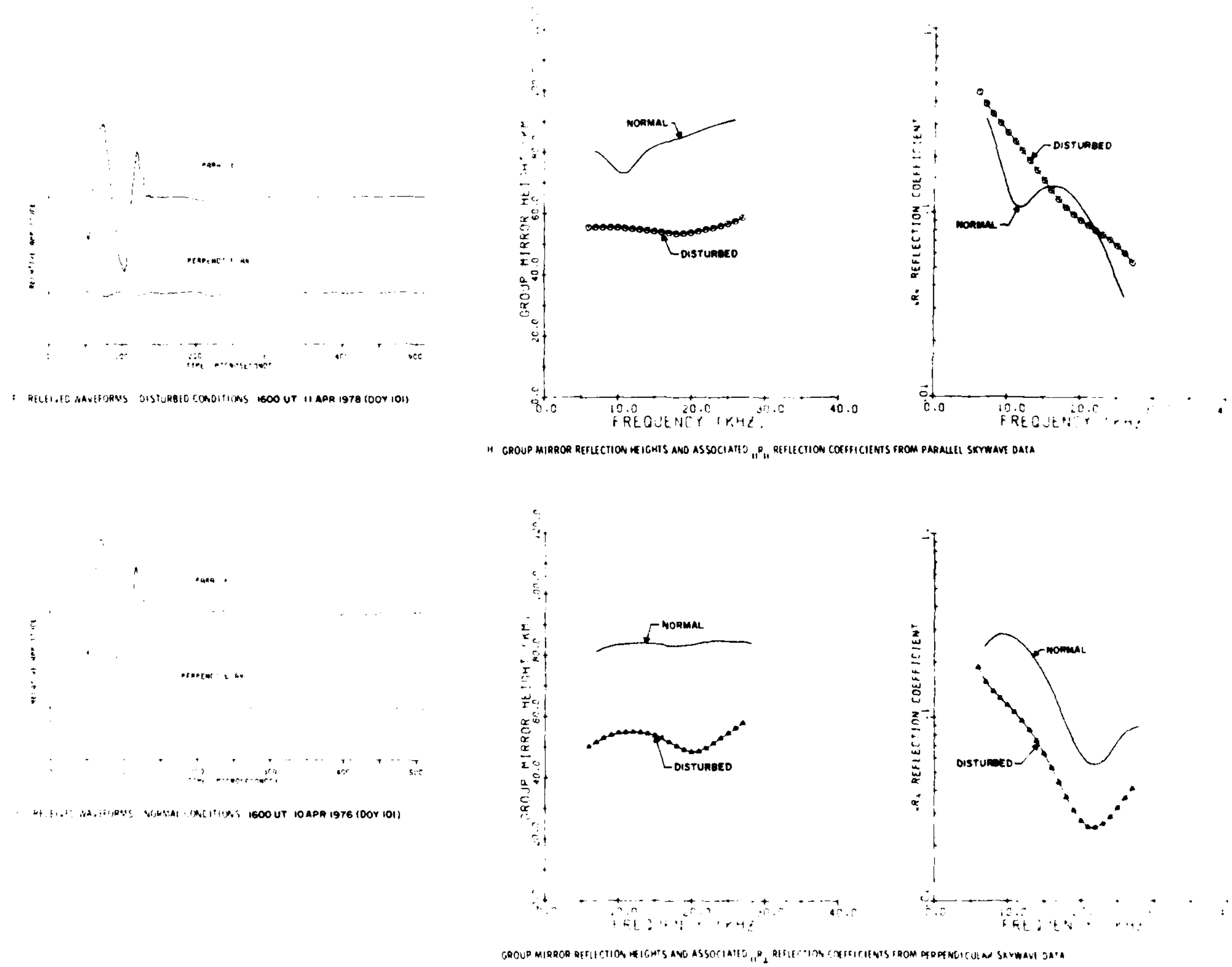
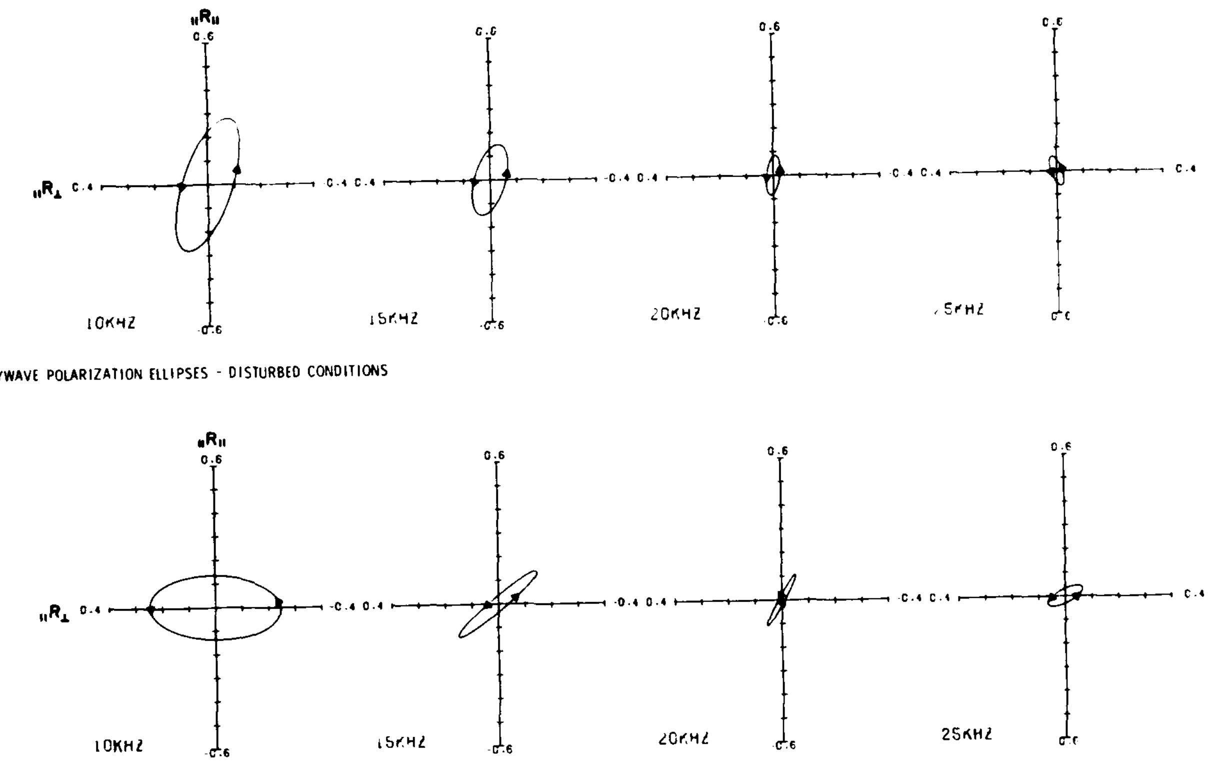


Figure 12. VLF/LF Ionospheric Reflectivity Data for 11 April 1978 (DAY 101) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS

K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 12. VLF/LF Ionospheric Reflectivity Data for 11 April 1978 (DAY 101) Solar Particle Event (Cont)

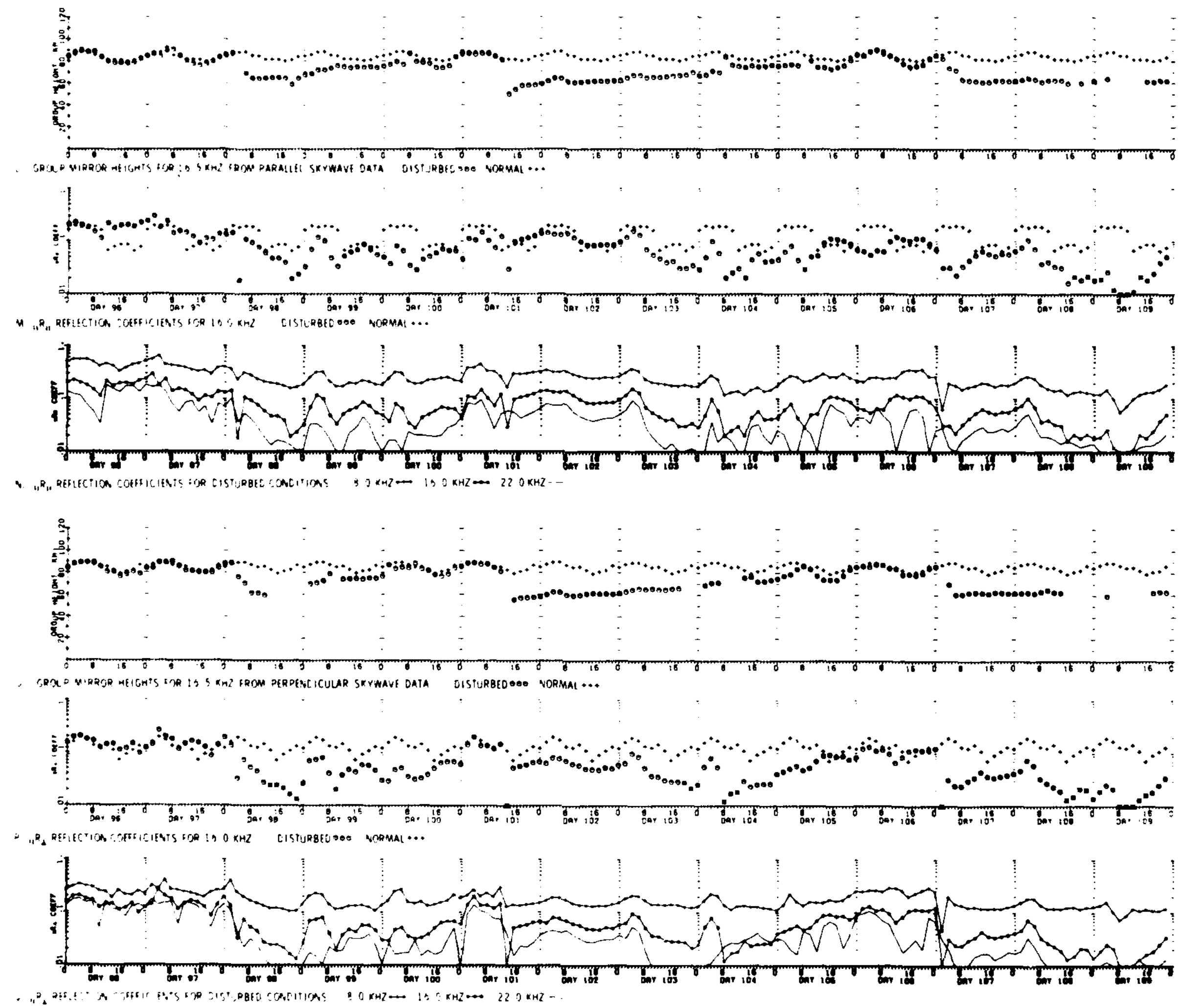


Figure 12. VLF/LF Ionospheric Reflectivity Data for 11 April 1978 (DAY 101) Solar Particle Event (Cont)

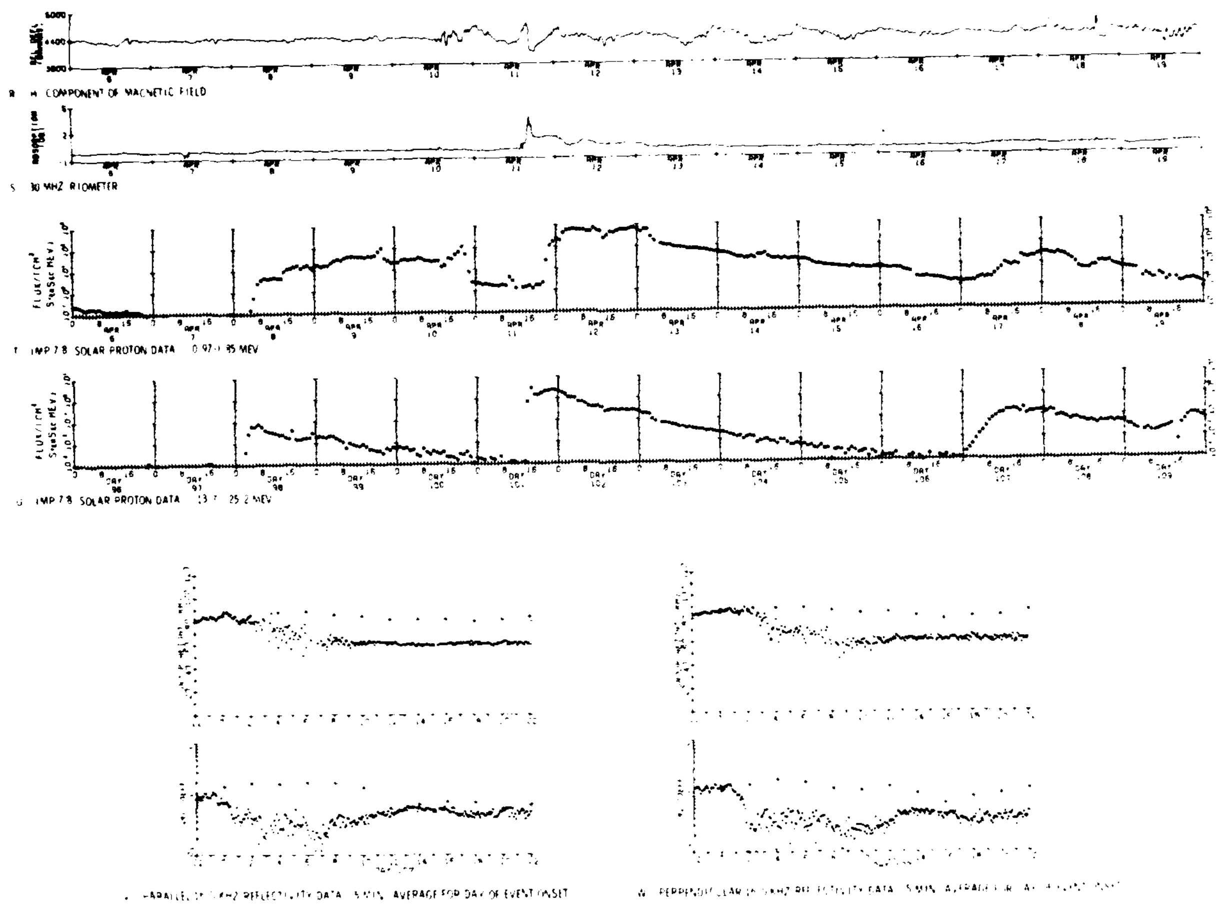
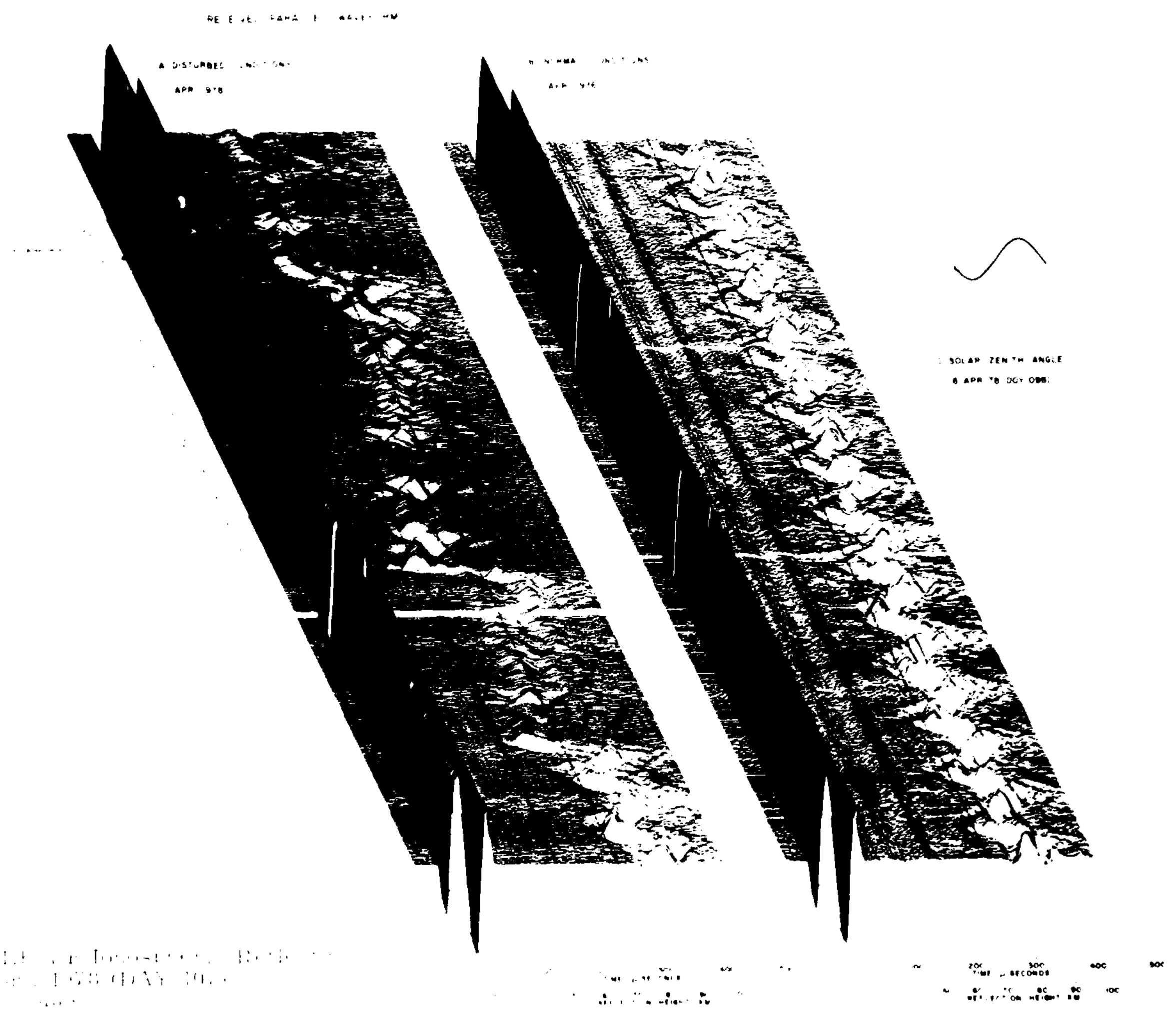


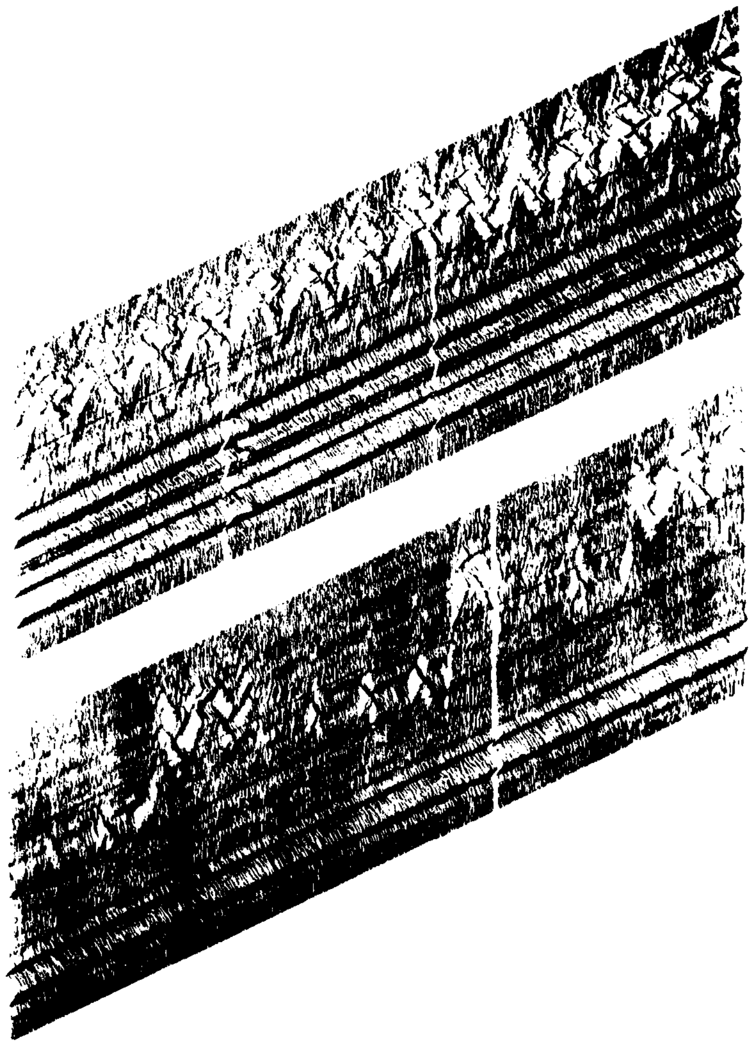
Figure 12. VLF/LF Ionospheric Reflectivity Data for 11 April 1978 (DAY 101) Solar Particle Event (Cont)

[illegible]

17 April 1978 Solar Particle Event

Date:	17 April	Day:	107
Report Figure:	13		
Related Solar Flare:		No data	X-ray class:
Start of Ionospheric Disturbance		0100 UT	
Time of Maximum 13-25 MeV Proton Flux:		1400 UT	
Maximum Flux:		0.2 particles/cm^2 sec sr MeV	
Length of Particle Event:		Continuing	
Lowest 16 kHz Reflection Height:		60 km	
30 MHz Riometer Absorption:		< 0.5 dB	
Solar Zenith Angle Range:		65° - 93°	
Illumination Conditions:		Daytime	


SOLAR ZENITH ANGLE
TIME, SECONDS
REFLECTION HEIGHT, KM



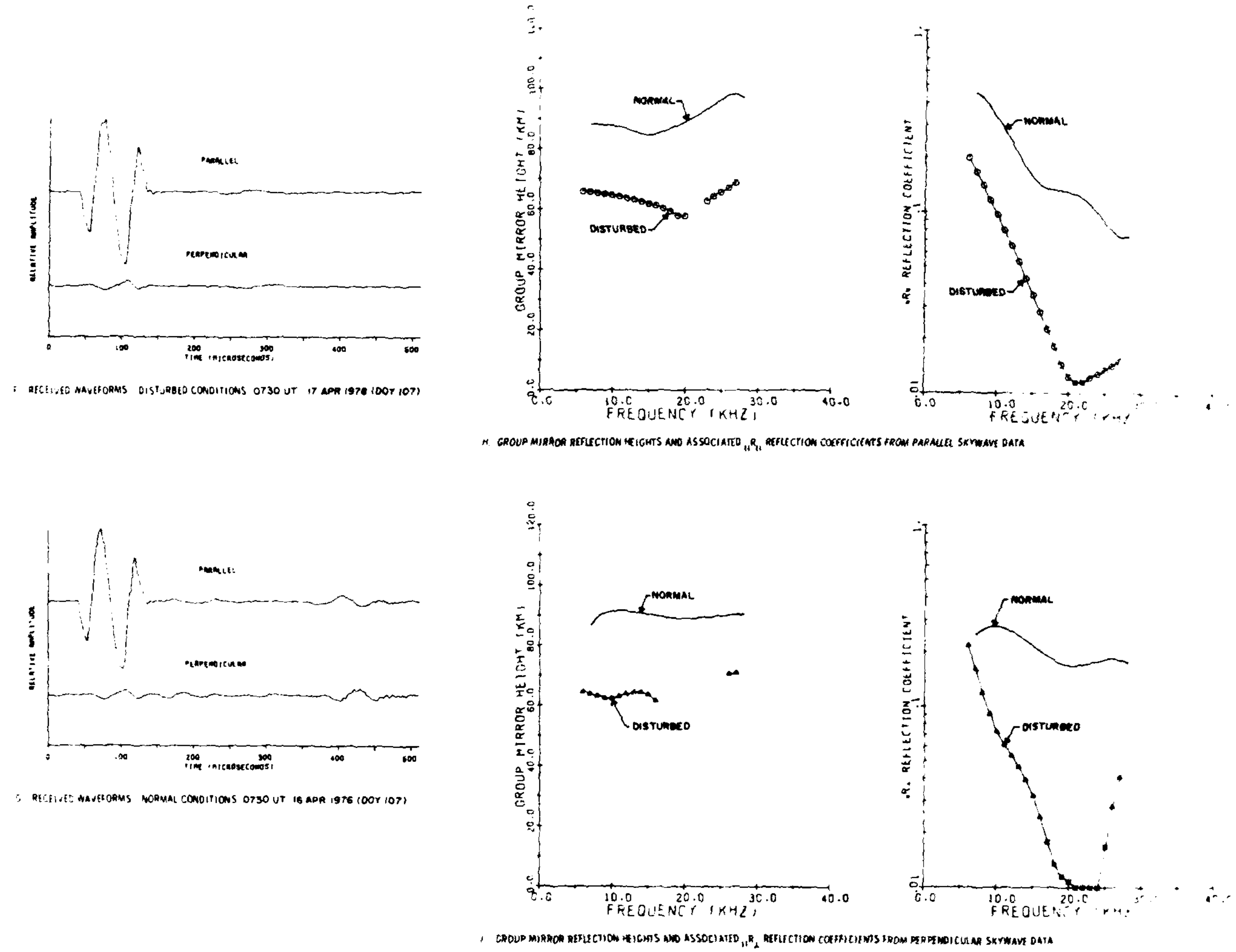
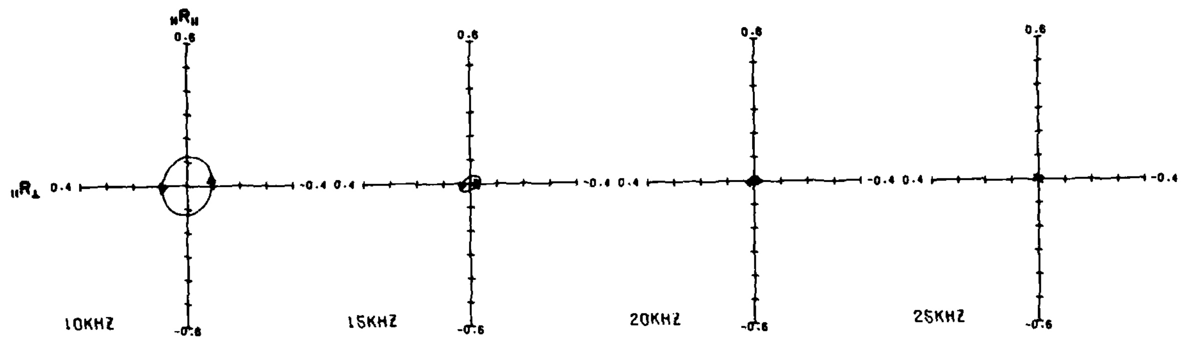
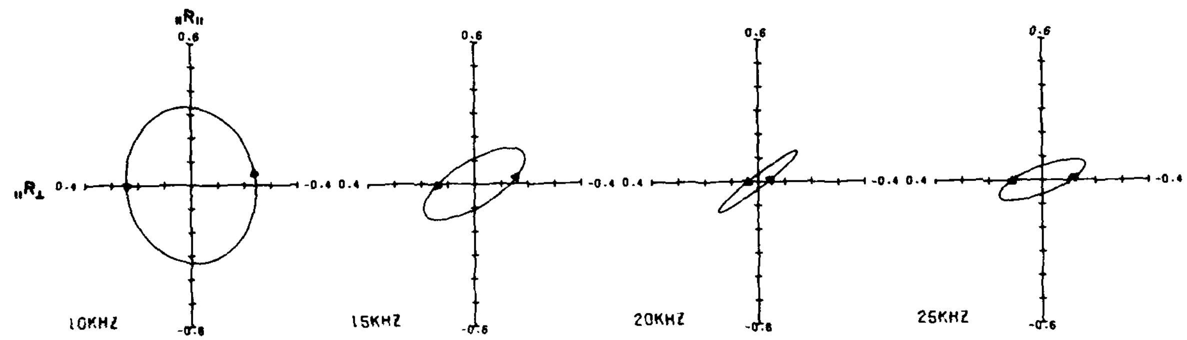


Figure 13. VLF/LF Ionospheric Reflectivity Data for 17 April 1978 (DAY 107) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 13. VLF/LF Ionospheric Reflectivity Data for 17 April 1978 (DAY 107) Solar Particle Event (Cont)

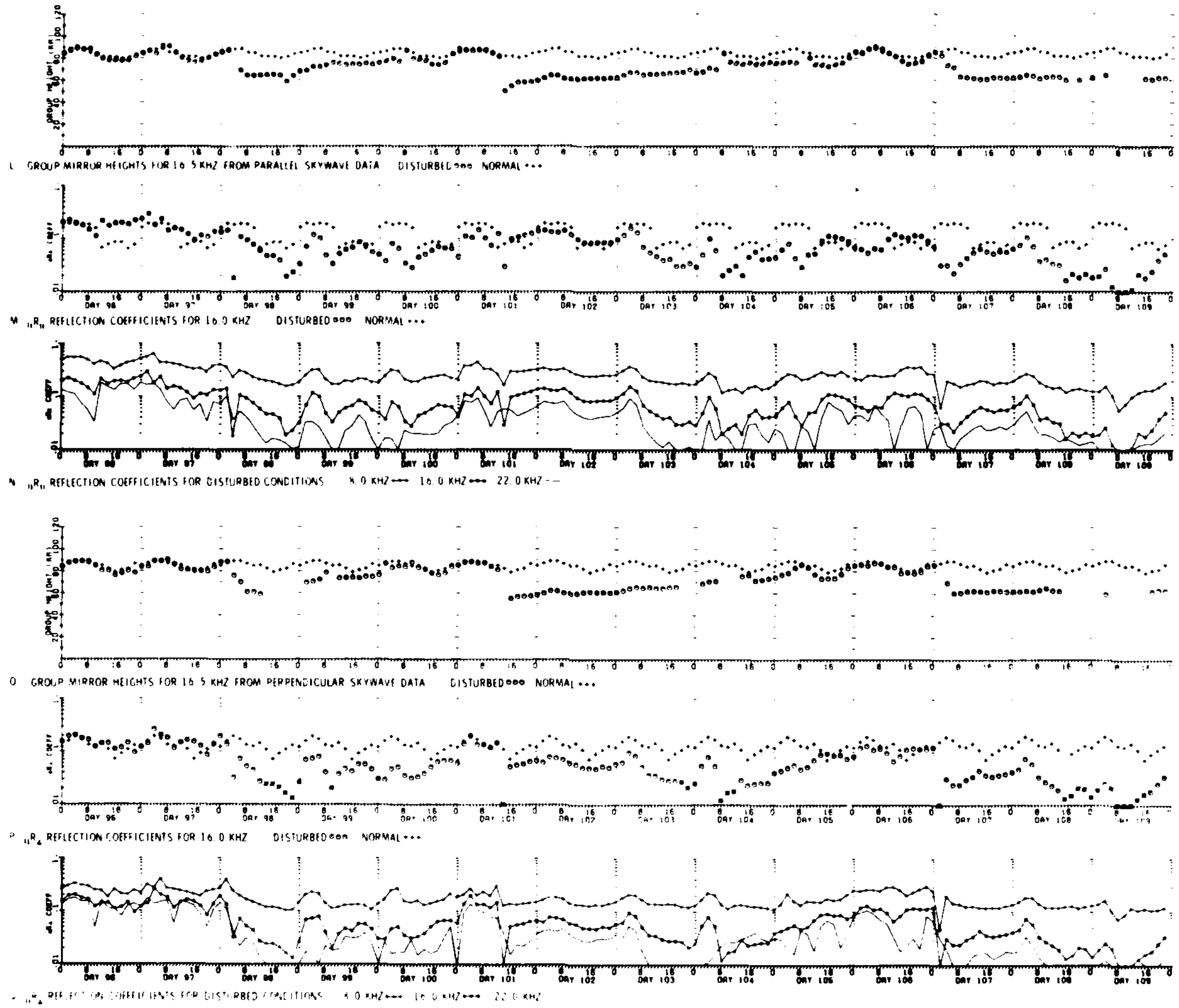


Figure 13. VLF/LF Ionospheric Reflectivity Data for 17 April 1978 (DAY 107) Solar Particle Event (Cont)

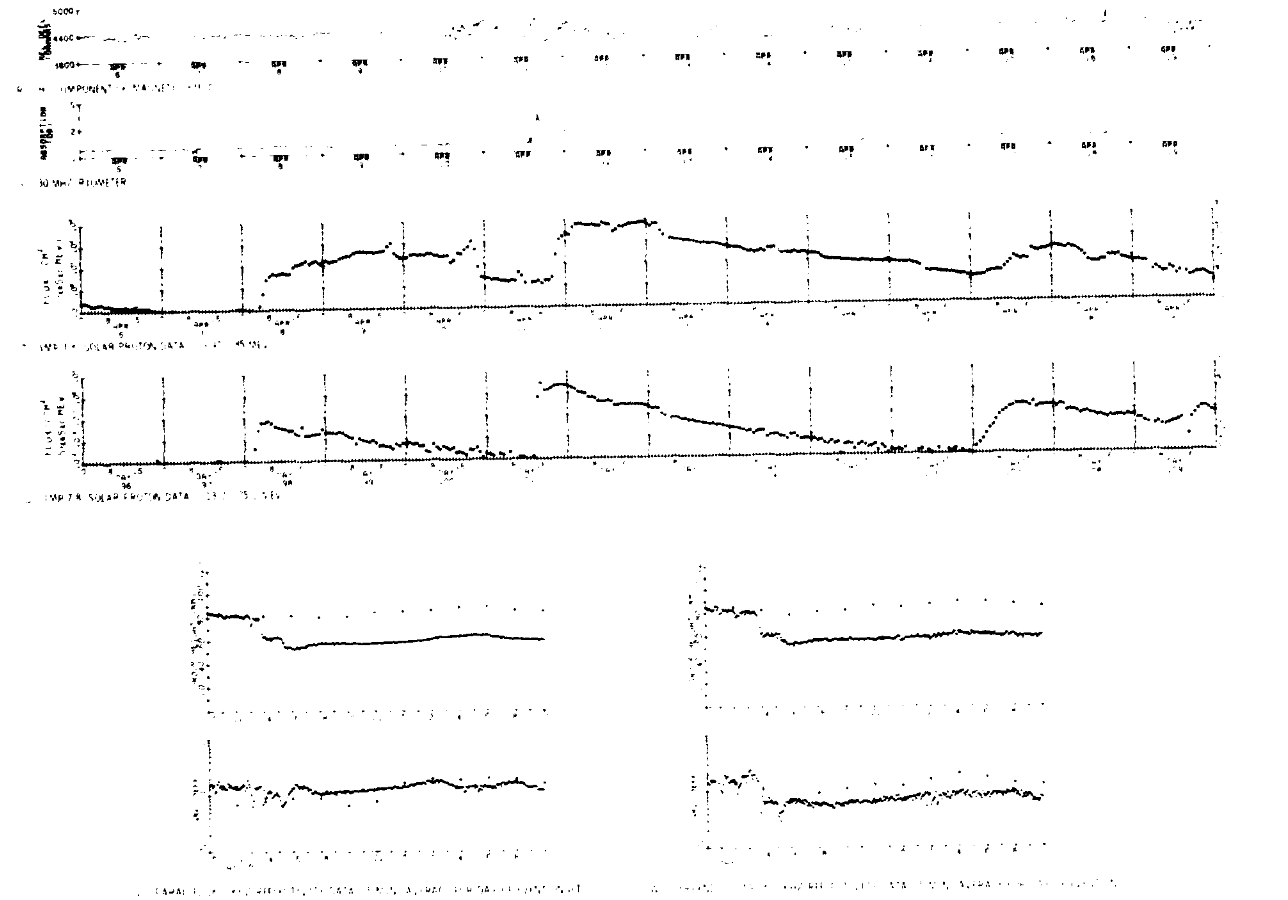
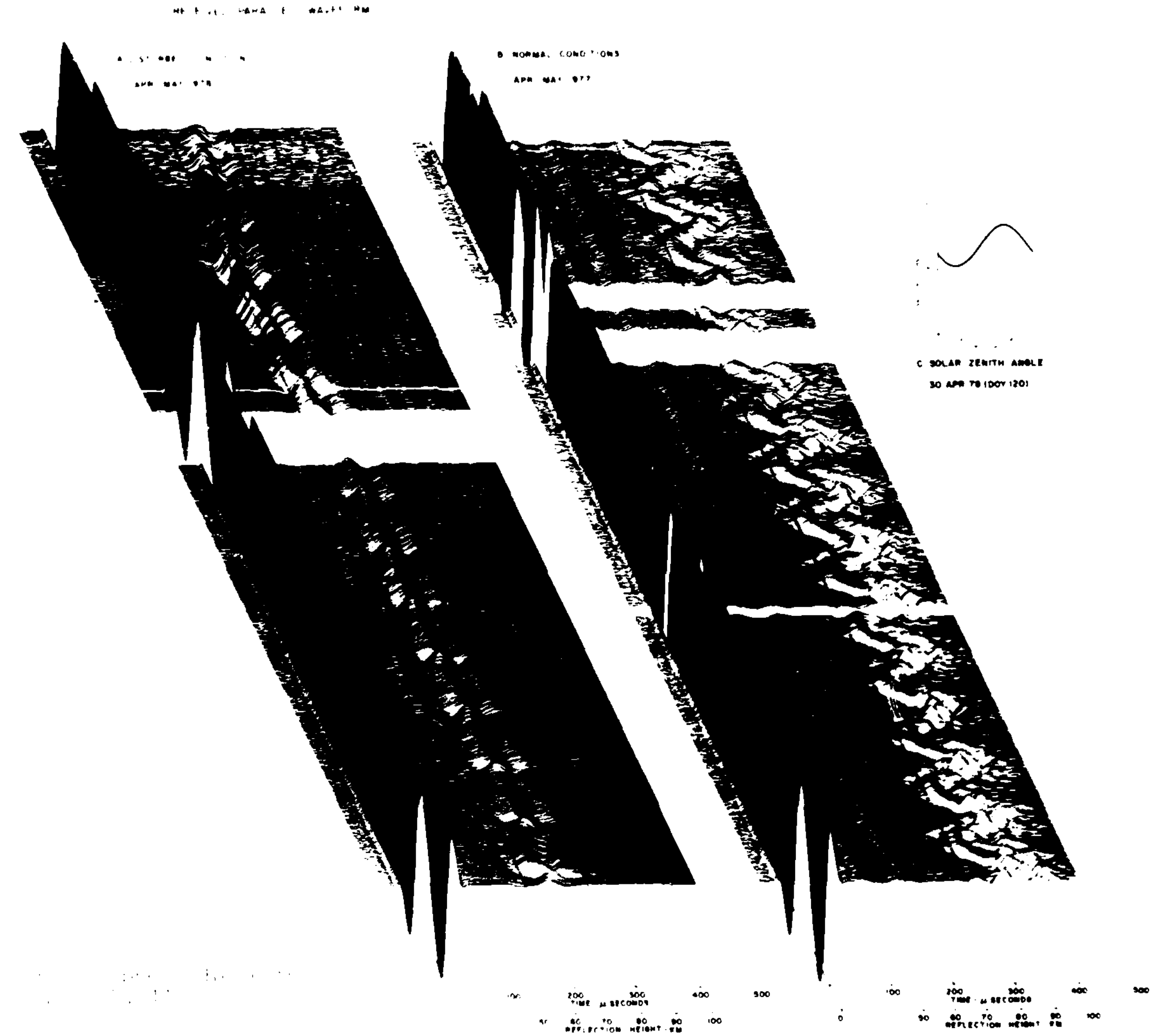


Figure 13. VLF/LF Ionospheric Reflectivity Data for 17 April 1978 (DAY 107) Solar Particle Event (Cont)

[illegible]

28 April 1978 Solar Particle Event

Date: 28 April	Day: 118		
Report Figure: 14			
Related Solar Flare:	1329 UT	X-ray class:	X5
	29 April 1925 UT		X3
	30 April 1508 UT		X2
Start of Ionospheric Disturbance:	No data		
Time of Maximum 13-25 MeV Proton Flux:	2000 UT 30 April		
Maximum Flux:	No data		
Length of Particle Event:	5 days		
Lowest 16 kHz Reflection Height:	About 57 km		
30 MHz Riometer Absorption:	9.8 dB		
Solar Zenith Angle Range:	60° - 88°		
Illumination Conditions:	Daytime		


B NORMAL CONDITIONS
C SOLAR ZENITH ANGLE
30 APR 78 (DOY 120)
100 200 300 400 500
TIME μ SECONDS
60 70 80 90 100
REFLECTION HEIGHT KM
0 100 200 300 400 500
TIME μ SECONDS
50 60 70 80 90 100
REFLECTION HEIGHT KM

FILTERED PERPENDICULAR

CONDITIONS

B 8

E NORMAL CONDITIONS

APR

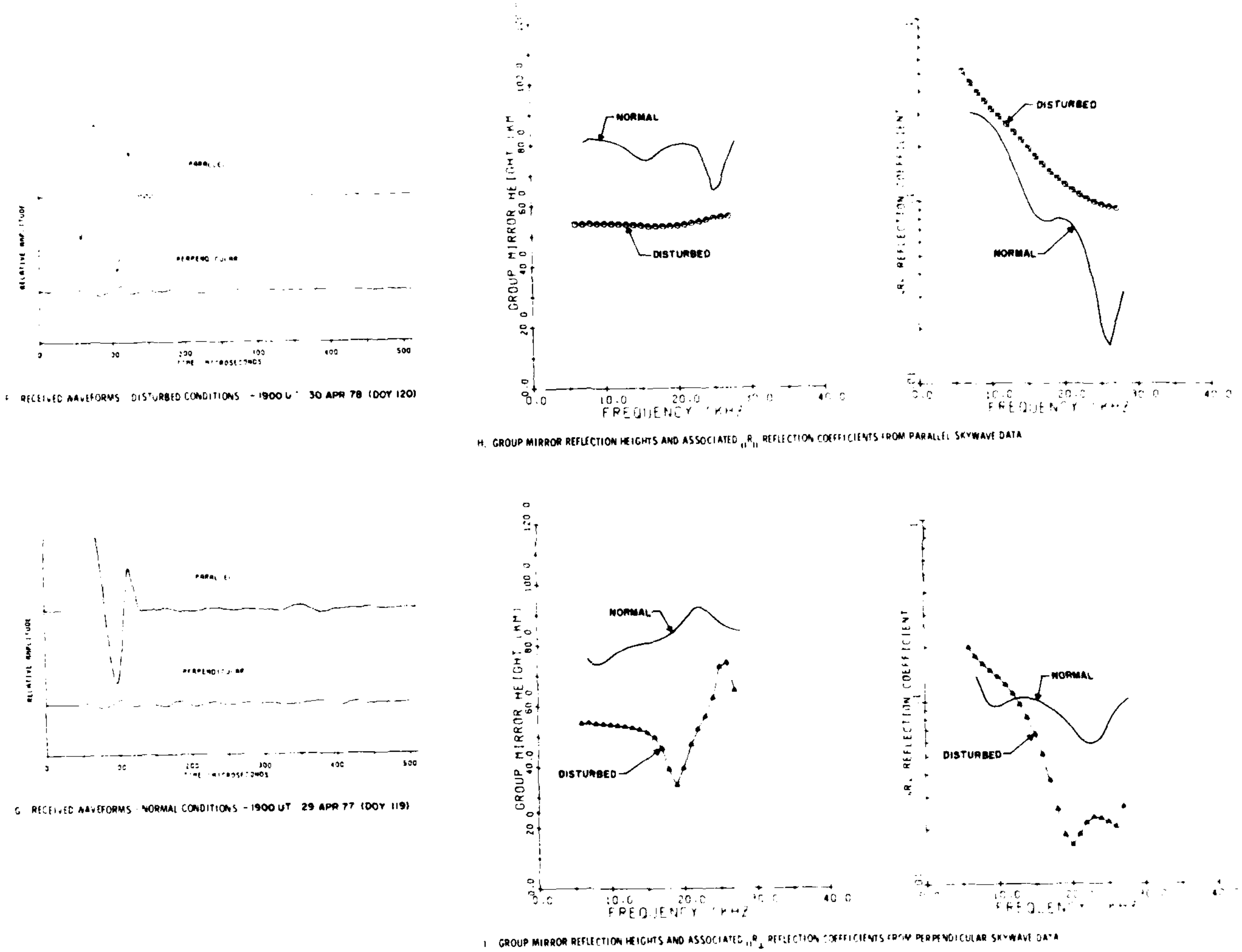
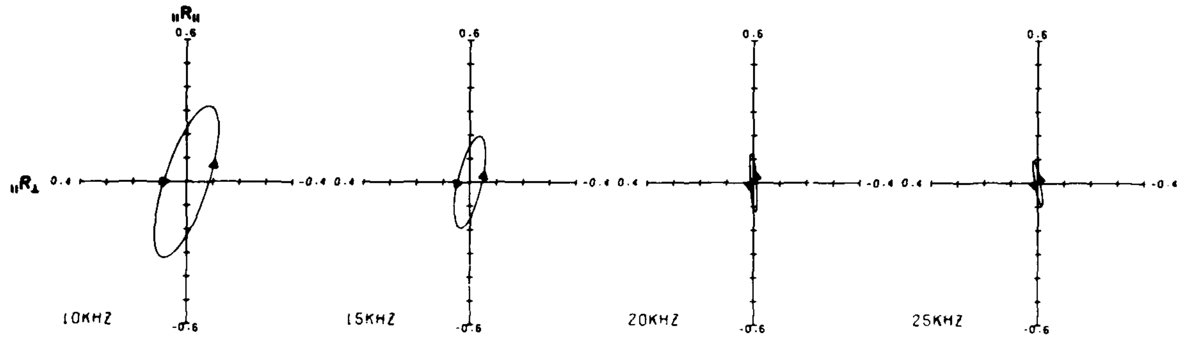
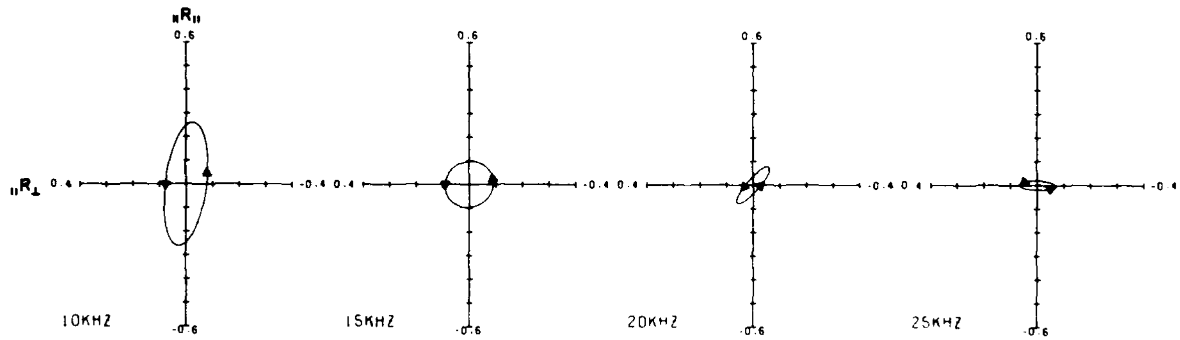


Figure 14. VLF/LF Ionospheric Reflectivity Data for 28 April 1978 (DAY 118) Solar Particle Fvent (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 14. VLF/LF Ionospheric Reflectivity Data for 28 April 1978 (DAY 118) Solar Particle Event (Cont)

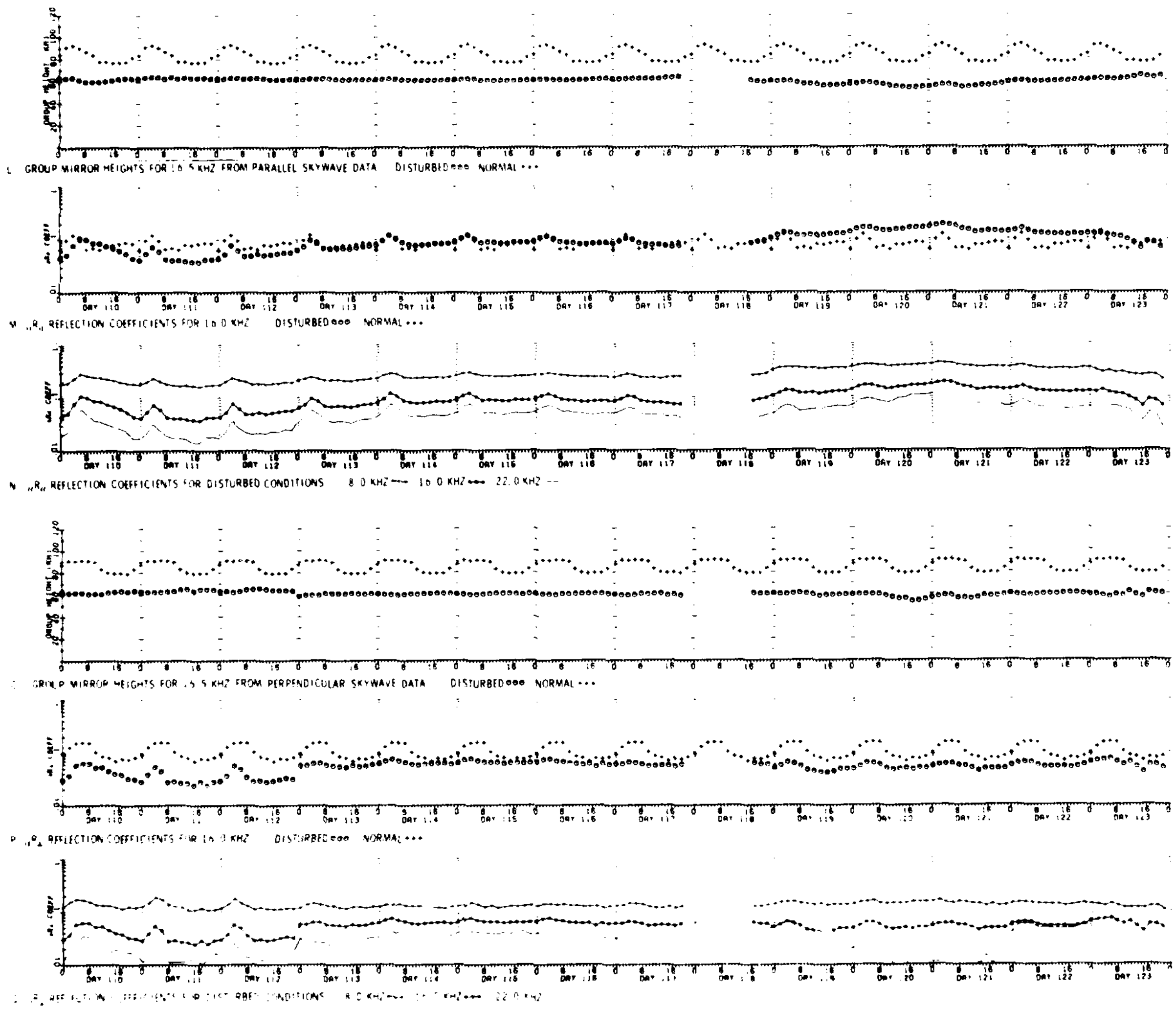


Figure 14. VLF/LF Ionospheric Reflectivity Data for 28 April 1978 (DAY 118) Solar Particle Event (Cont)

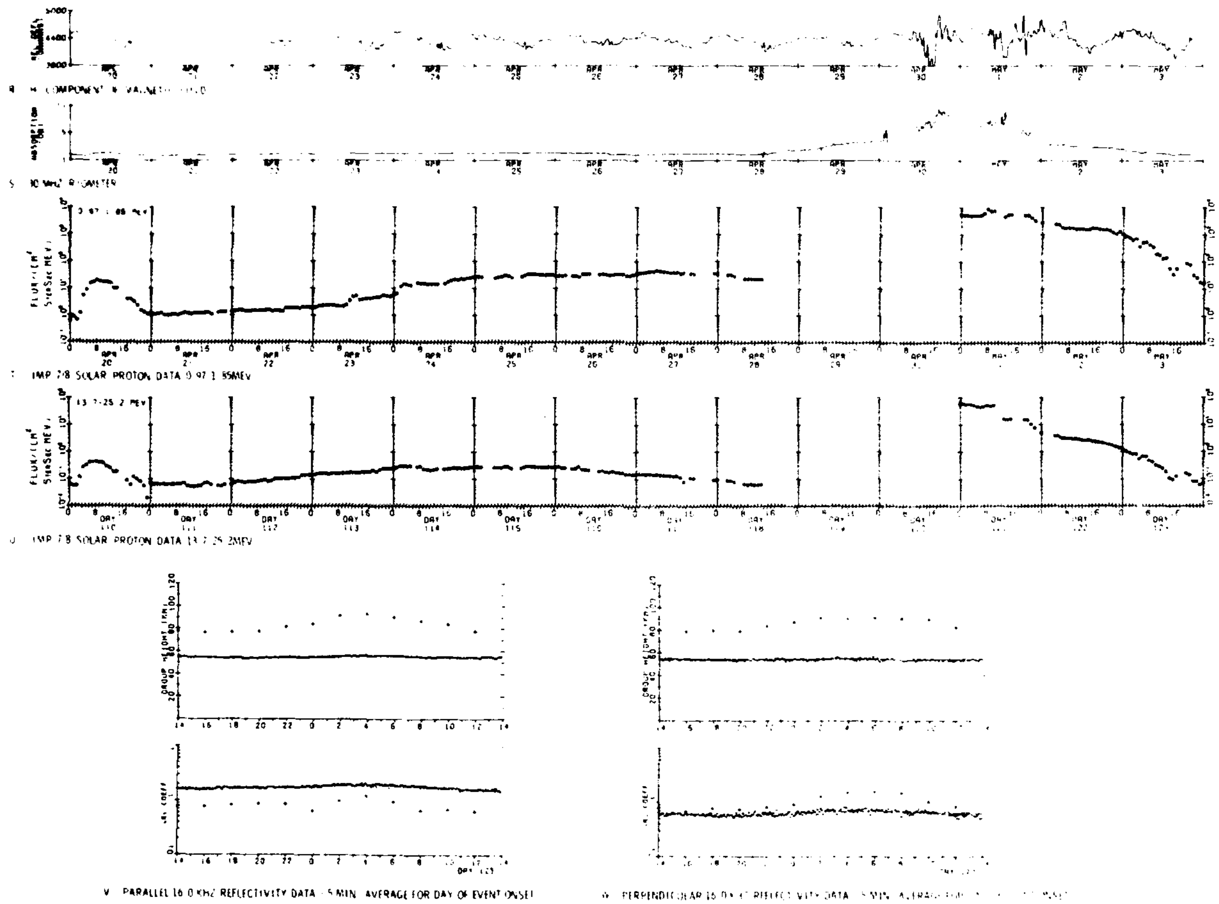


Figure 14. VLF/LF Ionospheric Reflectivity Data for 28 April 1978 (DAY 118) Solar Particle Event (Cont)

[illegible]

7 May 1978 Solar Particle Event

Date: 7 May	Day: 127
Report Figure: 15	
Related Solar Flare:	0331 UT X-ray [illegible]
Start of Ionospheric Disturbance:	0340 UT
Time of Maximum 13-25 MeV Proton Flux	0500 UT
Maximum Flux:	10 particles/cm^2 s sr MeV
Length of Particle Event:	Continuing
Lowest 16 kHz Reflection Height:	57 km
30 MHz Riometer Absorption:	1 dB
Solar Zenith Angle Range:	59° - 87°
Illumination Conditions:	Daytime

The reflection parameters during this event were typical of those seen during daytime conditions. The reflection heights showed a drop followed by a gradual return to normal. In contrast with the undisturbed conditions there was no diurnal height variation during the event. The effects of particle ionization override the small variation in solar ionizing radiation during the day. As is typical of daytime events reflection coefficients at event maximum were stronger than before the event. The maximum was followed by a gradual decrease, the 16 and 22 kHz $\parallel$ and $\perp$ coefficients dropped below pre-event levels several days after event maximum. The final recovery of 7 May event merged by another event which occurred on 11 May (DAY 131).

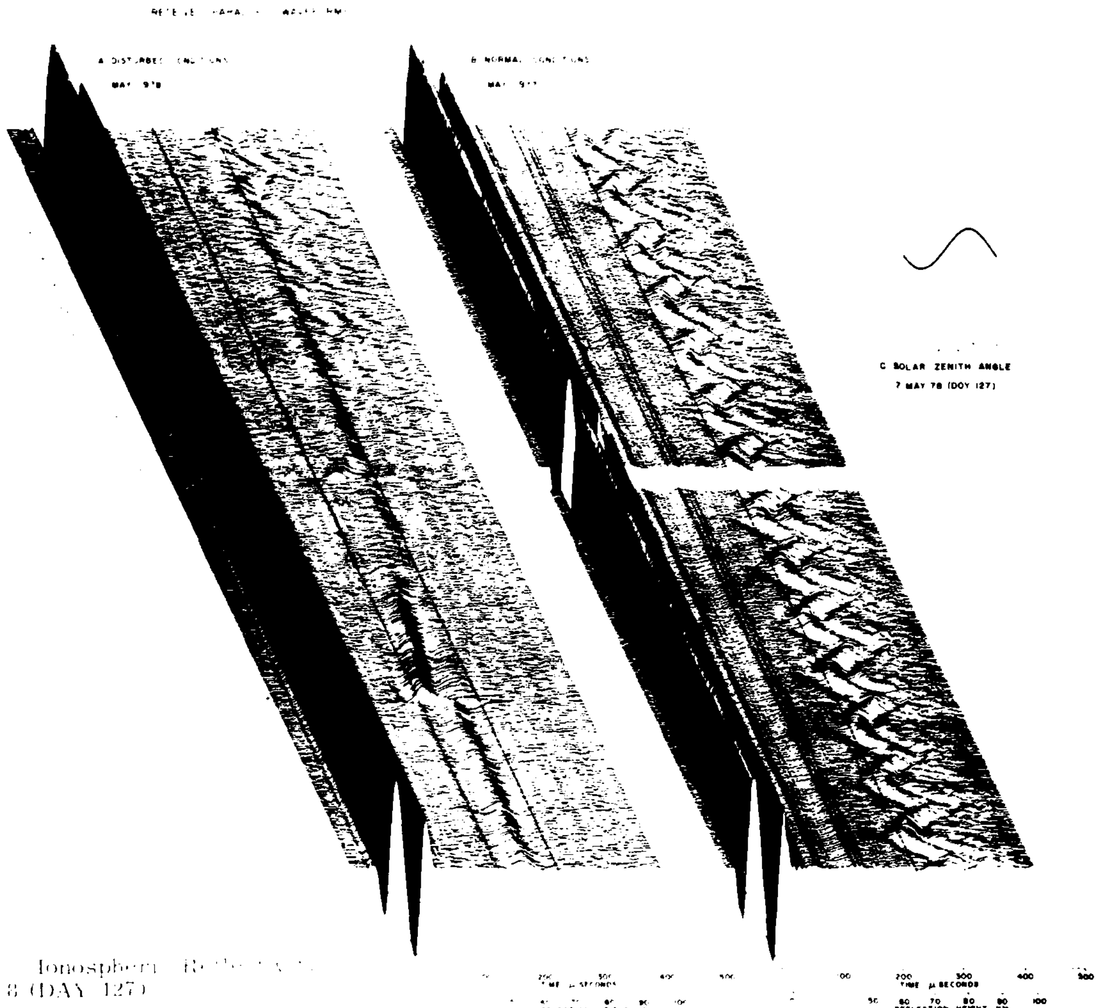


Figure 15. E Ionosphere Reflection Data for 7 May 1978 (DAY 127) Solar Particle Event

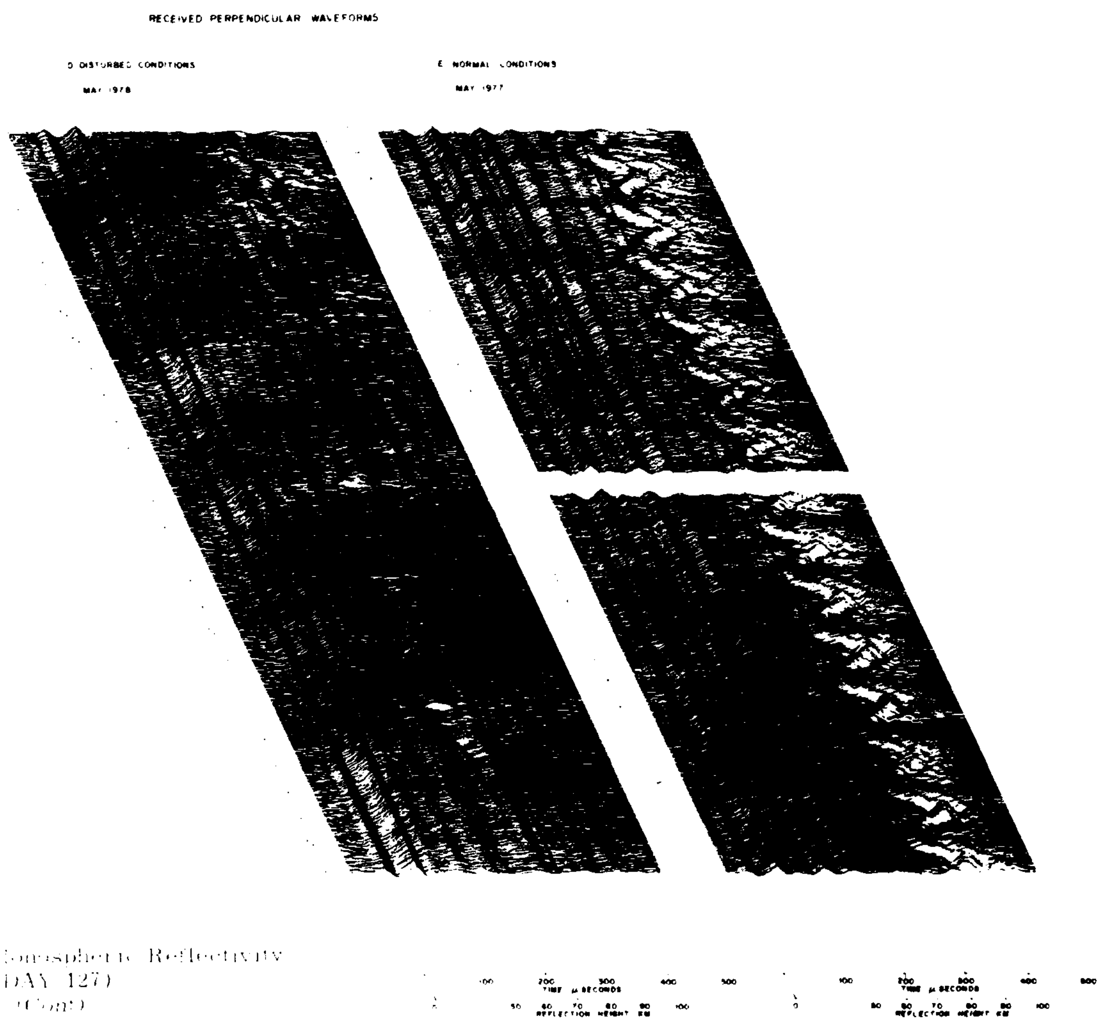


Figure [illegible] [illegible]LF [illegible] Ionospheric Reflectivity
Data [illegible] May 1978 (DAY 127)
Solar Particle Event (Cont)

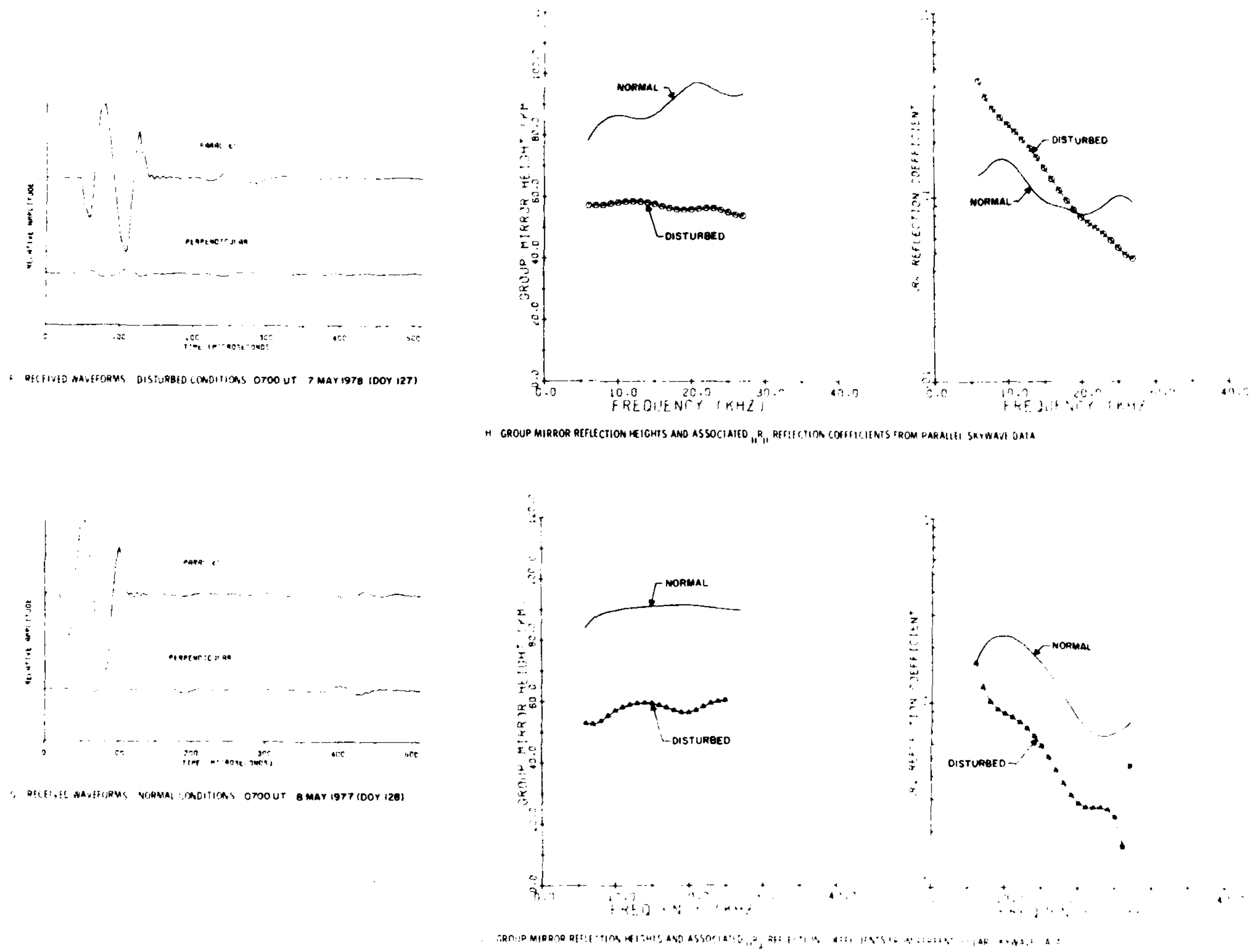
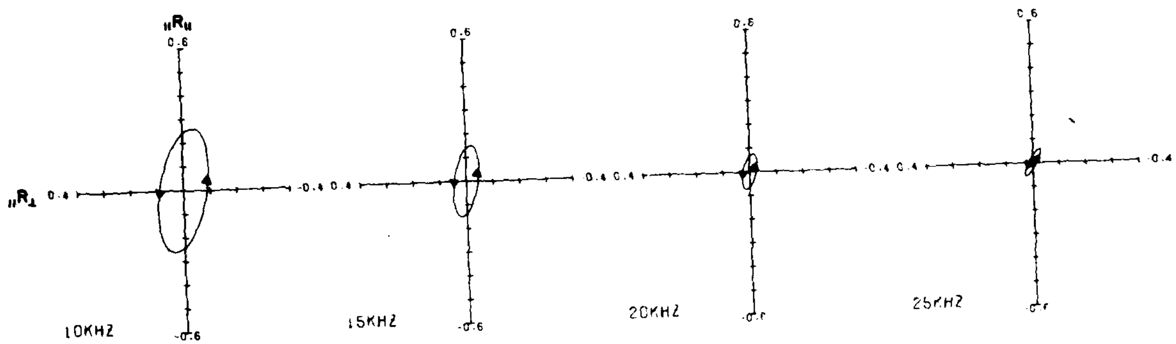
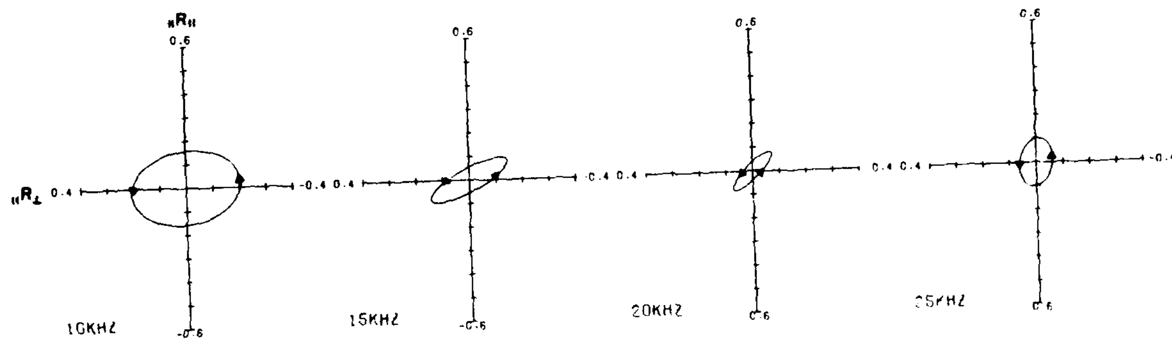


Figure 15. VLF/LF Ionospheric Reflectivity Data for 7 May 1978 (DAY 127) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 15. VLF/LF Ionospheric Reflectivity Data for 7 May 1978 (DAY 127) Solar Particle Event (Cont)

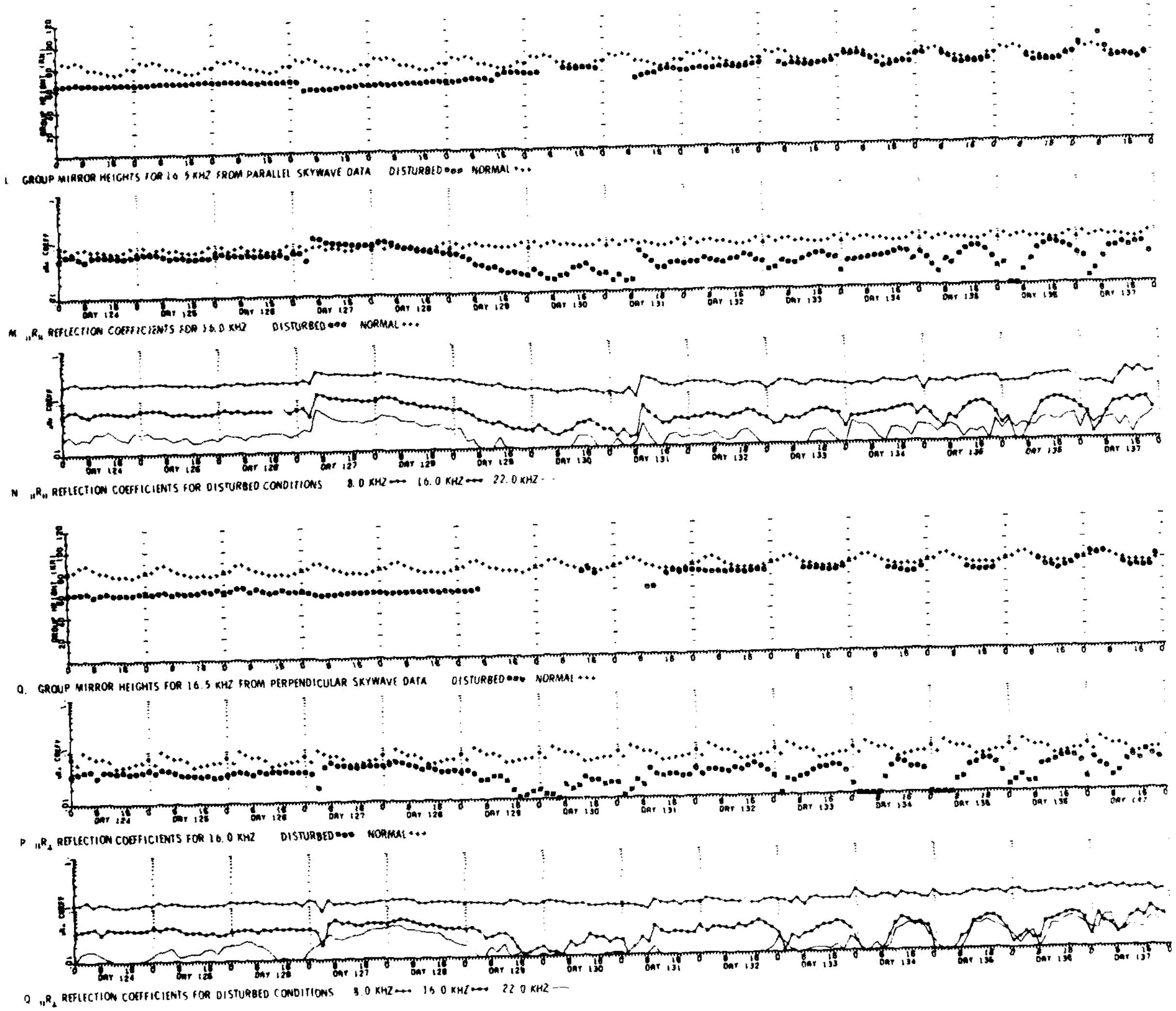
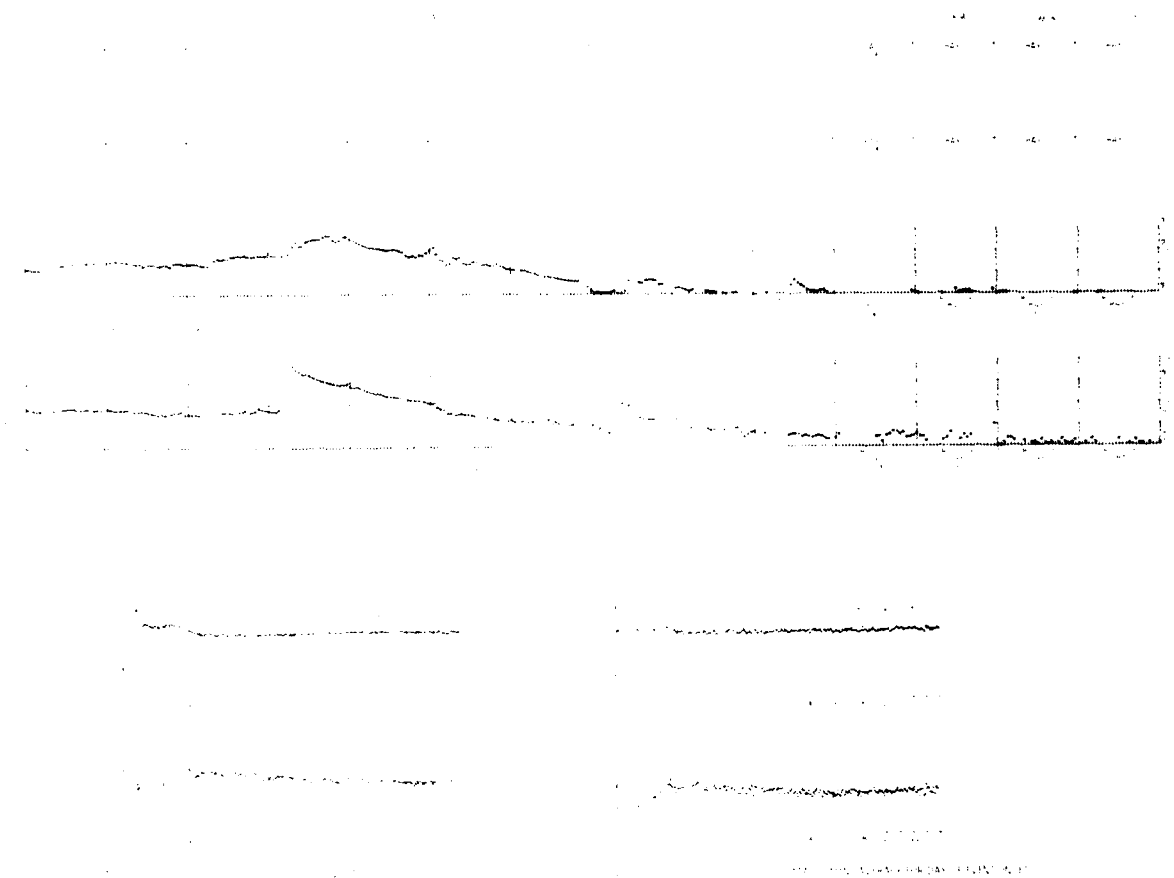


Figure 15. VLF/LF Ionospheric Reflectivity Data for 7 May 1978 (DAY 127) Solar Particle Event (Cont)



… 127) Solar Particle Event (Cont)

11 May 1978 Solar Particle Event

Date:	11 May	Day:	131
Report Figure:	16		
Related Solar Flare:		No data	X-ray class:
Start of Ionospheric Disturbance:		0800 UT	
Time of Maximum 13-25 MeV Proton Flux:		0900 UT	
Maximum Flux:		0.1 particle/cm^2 sec sr MeV	
Length of Particle Event:		1 day	
Lowest 16 kHz Reflection Height:		63 km	
30 MHz Riometer Absorption:		< 0.5 dB	
Solar Zenith Angle Range:		58° - 86°	
Illumination Conditions:		Daytime	

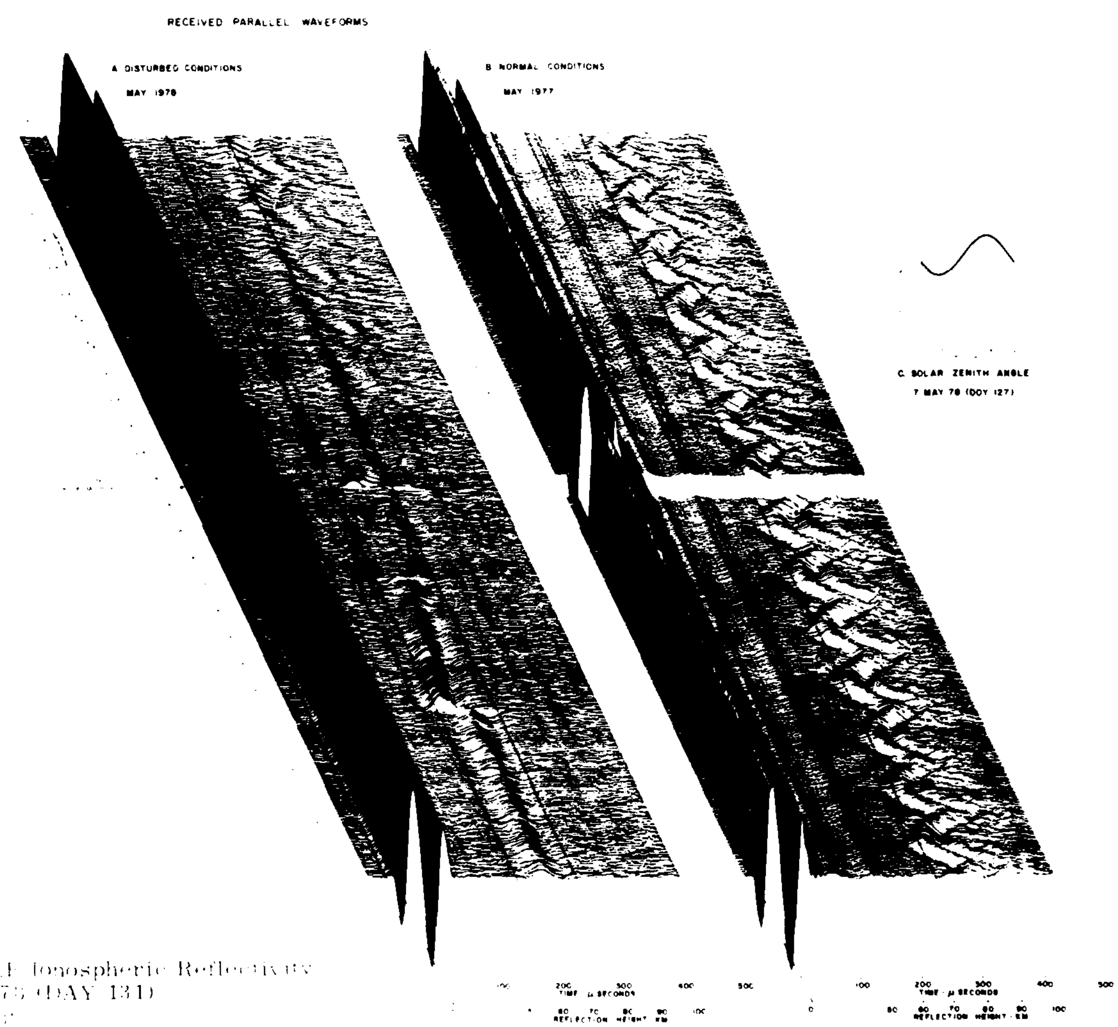
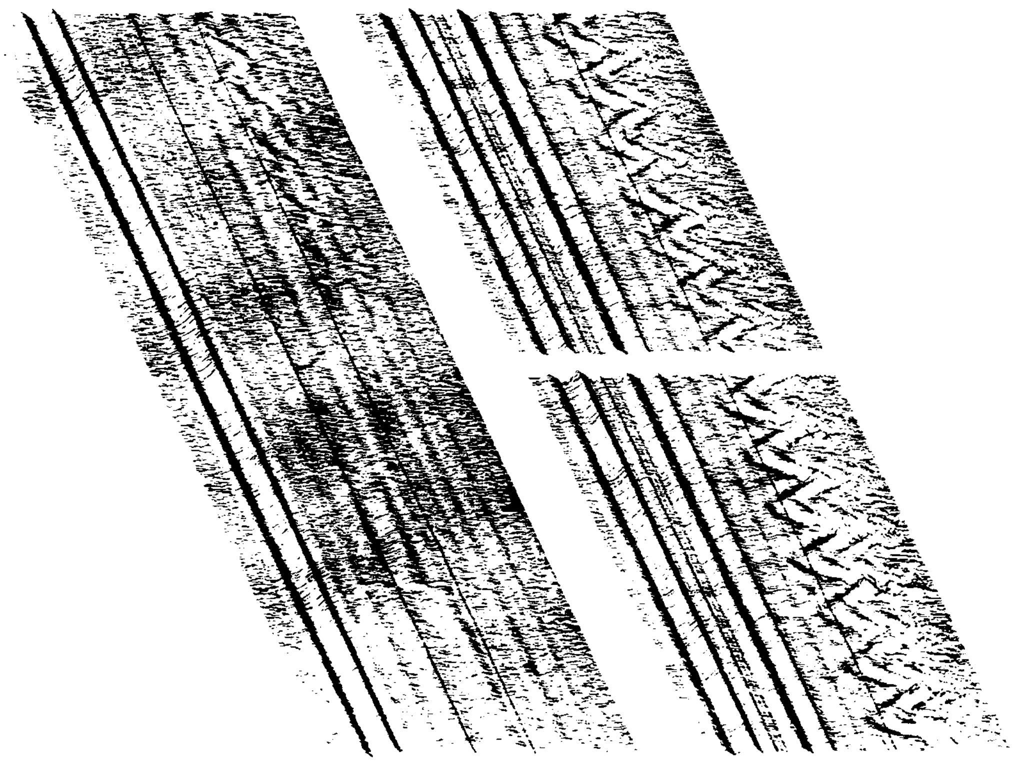


Figure 16. VLF-LF Ionospheric Reflectivity
During 11 May 1978 (DAY 131)
Solar Particle Event

...PERPENDICULAR WAKE...

...NORMAL CONDITIONS



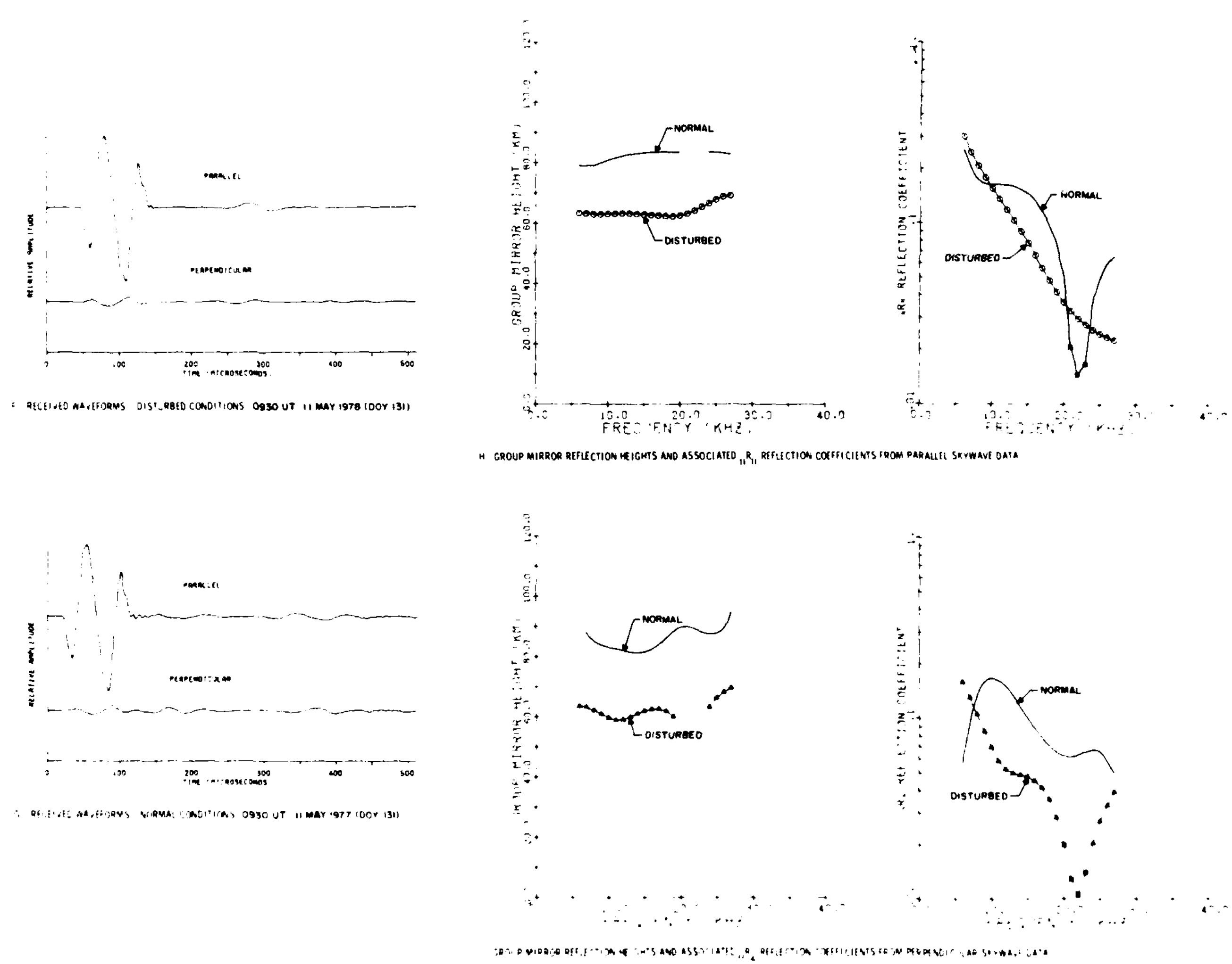
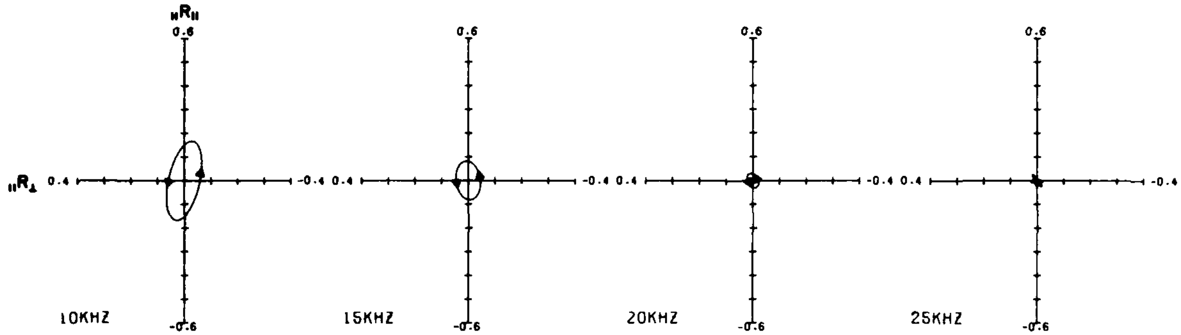
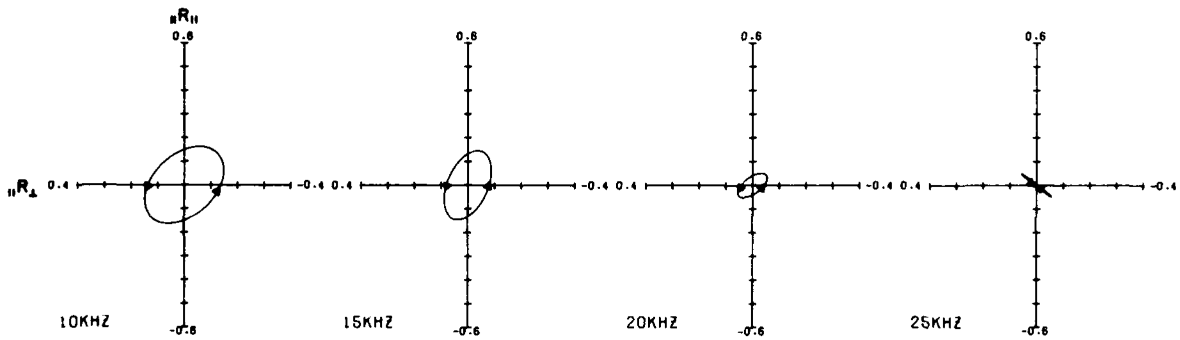


Figure 16. VLF/LF Ionospheric Reflectivity Data for 11 May 1978 (DAY 131) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 16. VLF/LF Ionospheric Reflectivity Data for 11 May 1979 (DAY 131) Solar Particle Event (Cont)

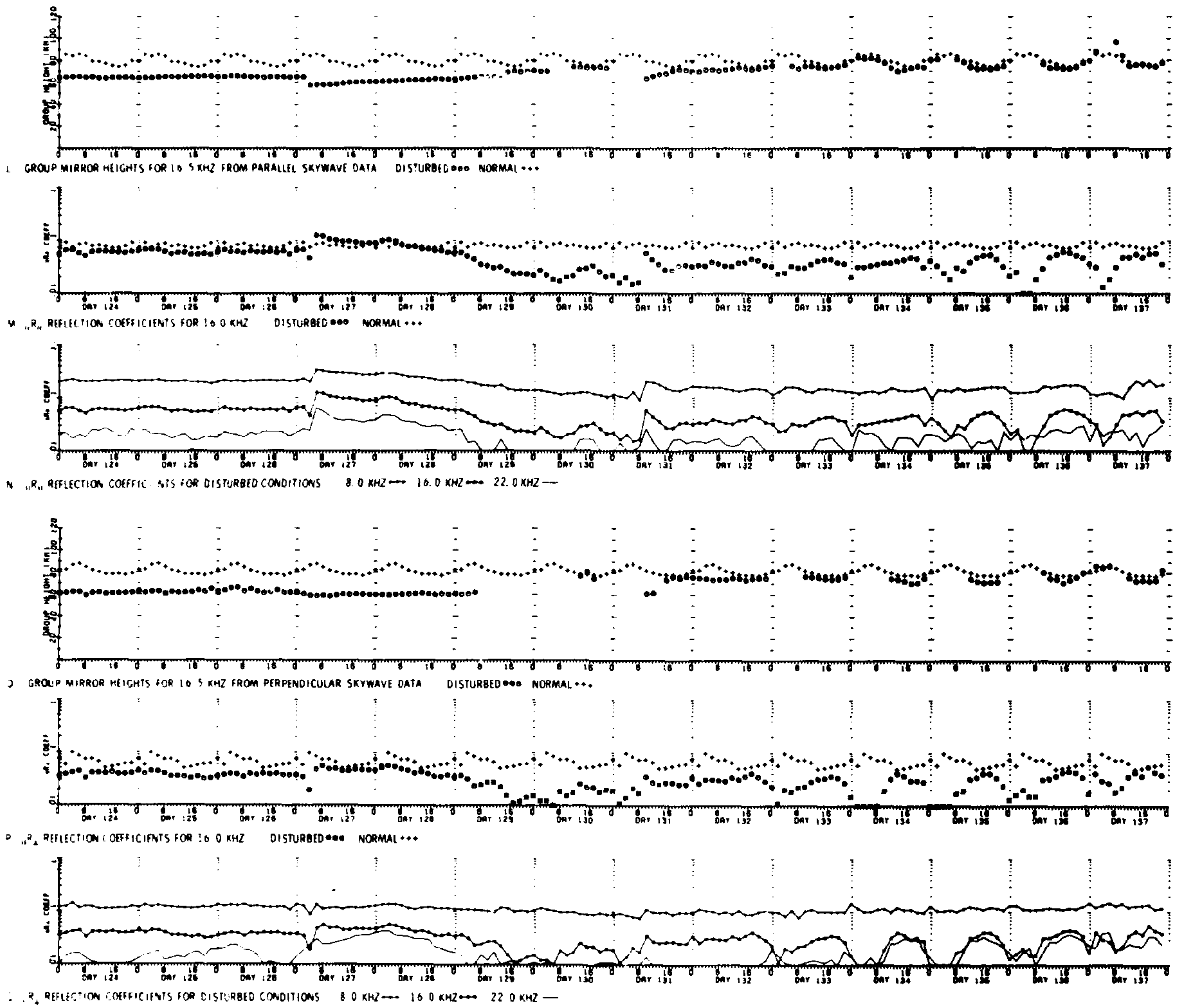


Figure 16. VLF/LF Ionospheric Reflectivity Data for 11 May 1978 (DAY 131) Solar Particle Event (Cont)

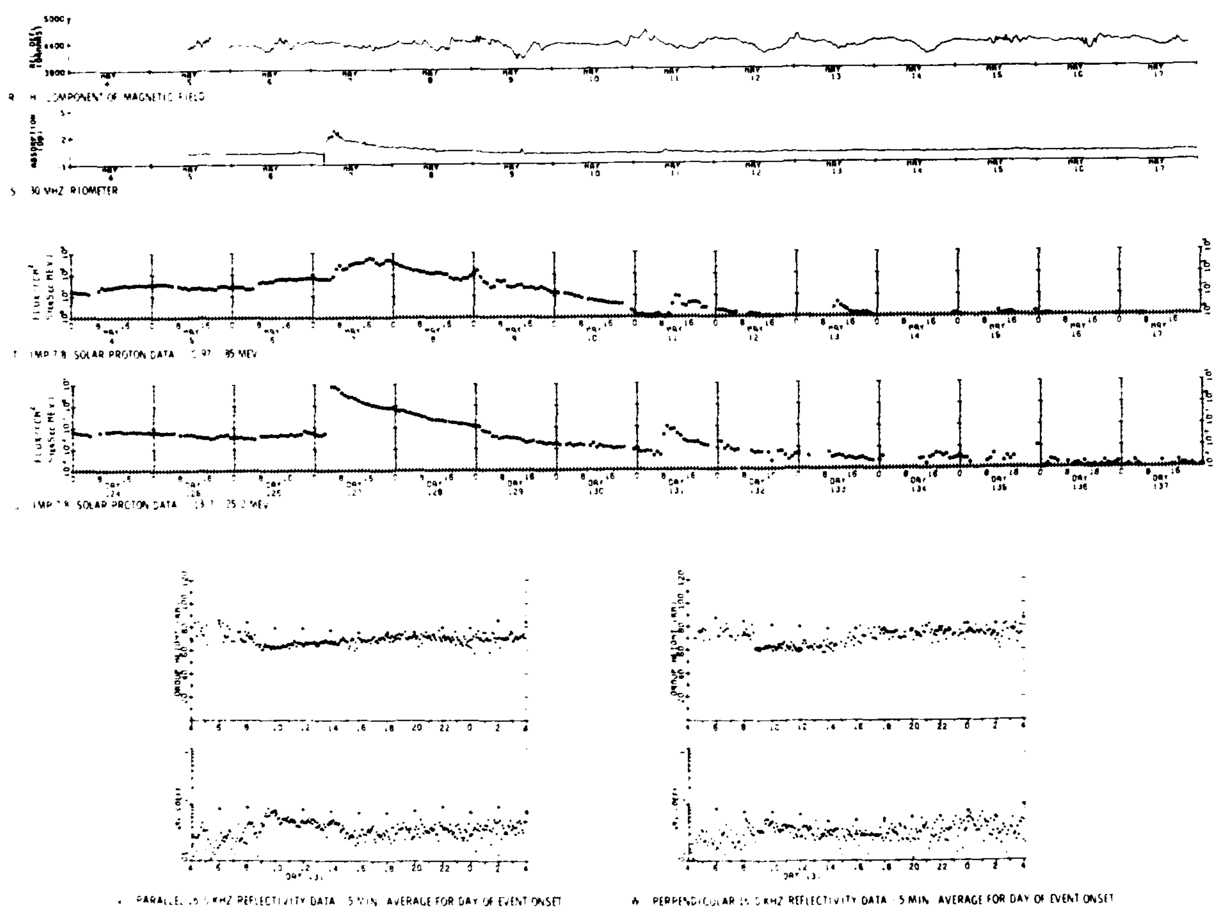


Figure 16. VLF/LF Ionospheric Reflectivity Data for 11 May 1978 (DAY 131) Solar Particle Event (Cont)

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31 May 1978 Solar Particle Event

Date:	31 May	Day:	151
Report Figure:	17		
Related Solar Flare:		No data	X-ray class:
Start of Ionospheric Disturbance:		1000 UT	
Time of Maximum 13-25 MeV Proton Flux:		1400 UT	
Maximum Flux:		0.4 particles/cm^2 sec sr MeV	
Length of Particle Event:		3 days	
Lowest 16 kHz Reflection Height:		63 km	
30 MHz Riometer Absorption:		1 dB	
Solar Zenith Angle Range:		53° - 81°	
Illumination Conditions:		Daytime	

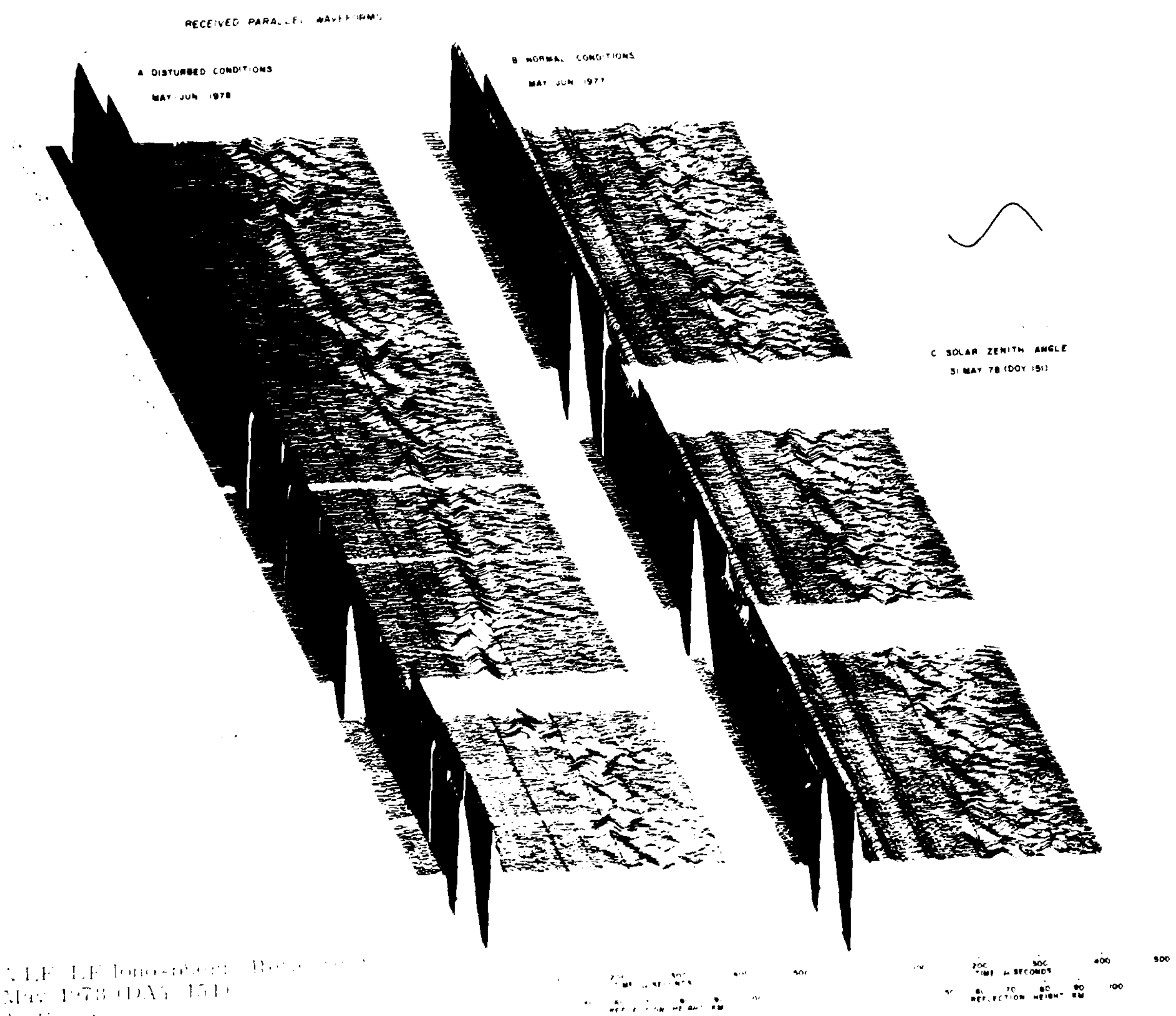


Figure 17. VLF/LF Ionospheric Re[illegible]
Data for 31 May 1978 (DAY 151)
Solar Particle Event

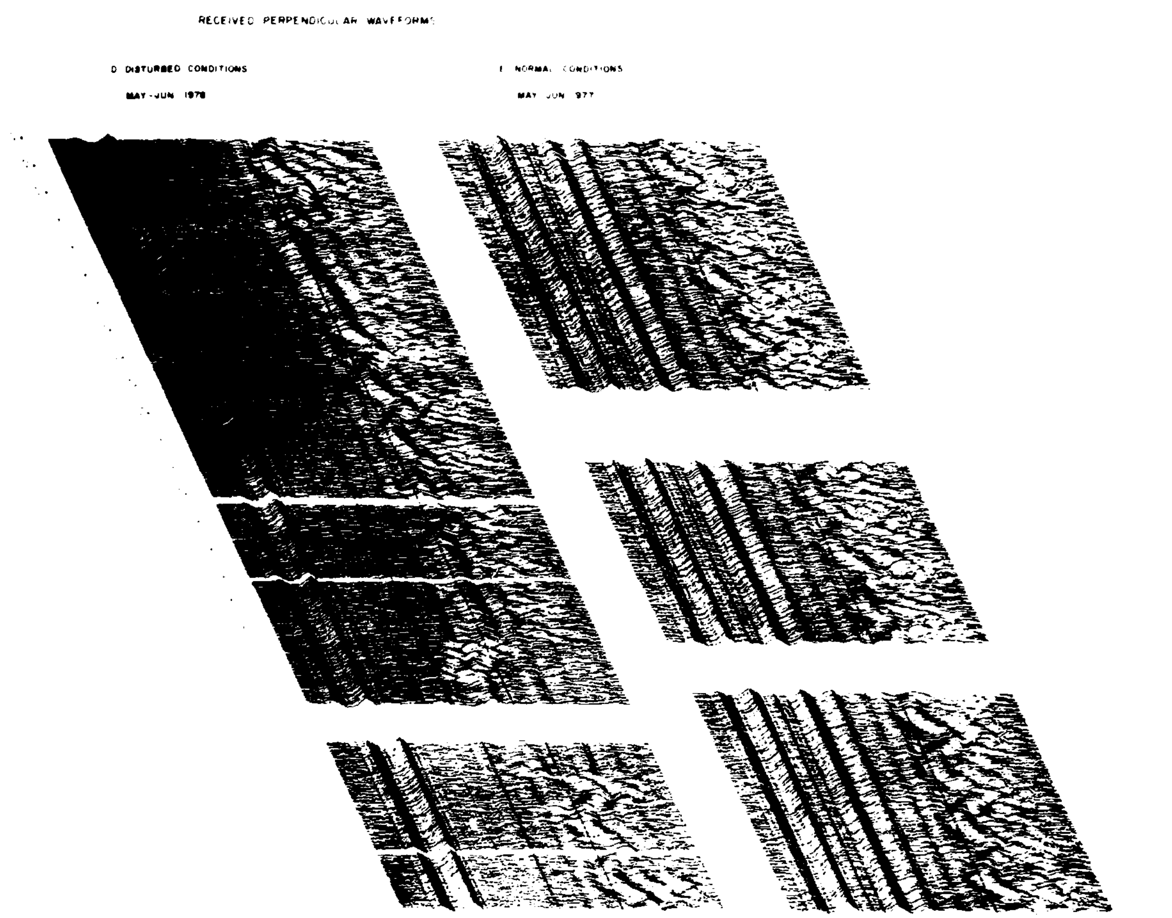
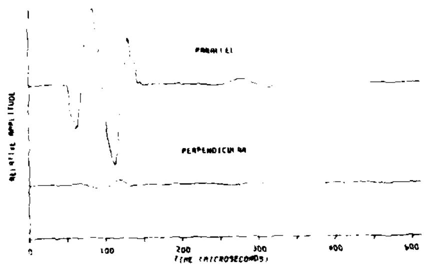
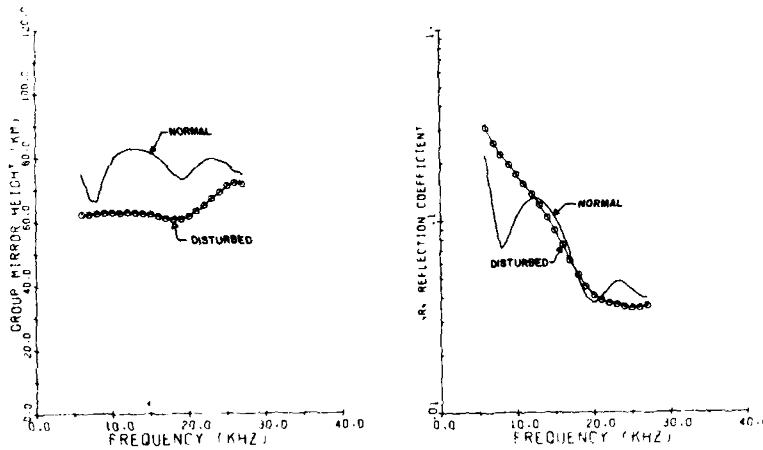


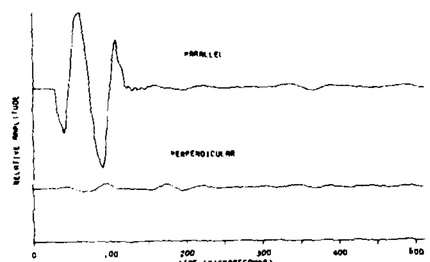
Figure 17. VLF/LF Ionospheric Reflection Data for 31 May 1978 (DAY 151) Solar Particle Event (Cont)



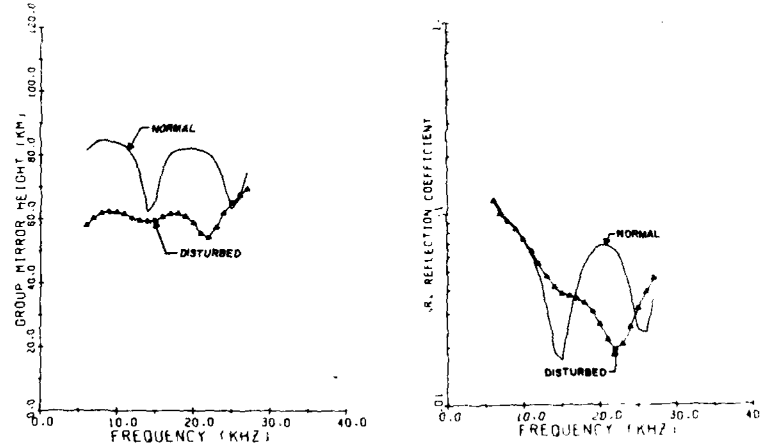
F. RECEIVED WAVEFORMS DISTURBED CONDITIONS 1330 UT 31 MAY 1978 (DOY 151)



H. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



G. RECEIVED WAVEFORMS NORMAL CONDITIONS 1330 UT 31 MAY 1977 (DOY 151)

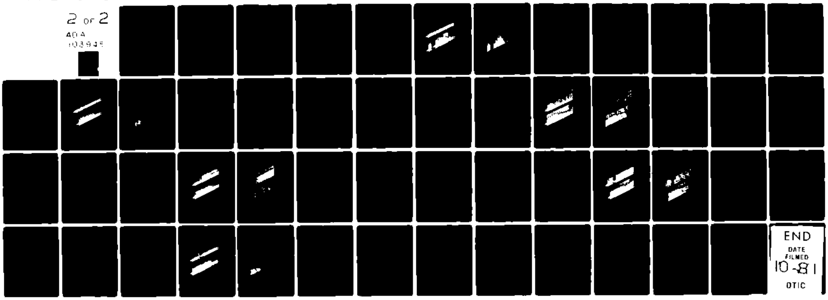


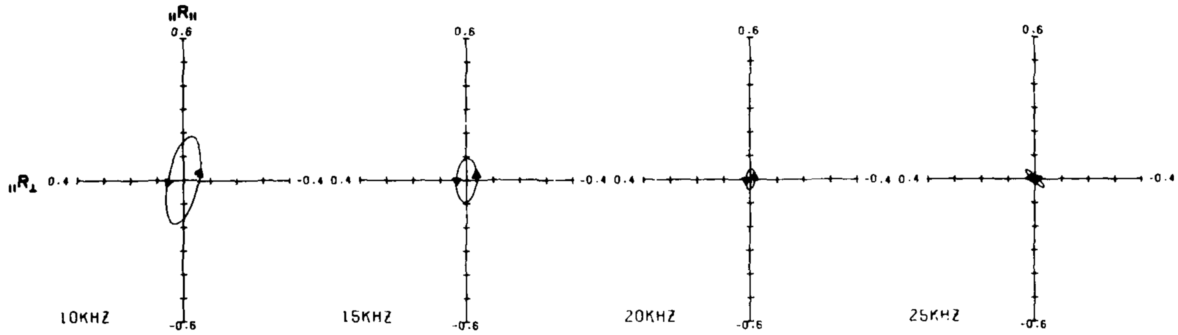
I. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 17. VLF/LF Ionospheric Reflectivity Data for 31 May 1978 (DAY 151) Solar Particle Event (Cont)

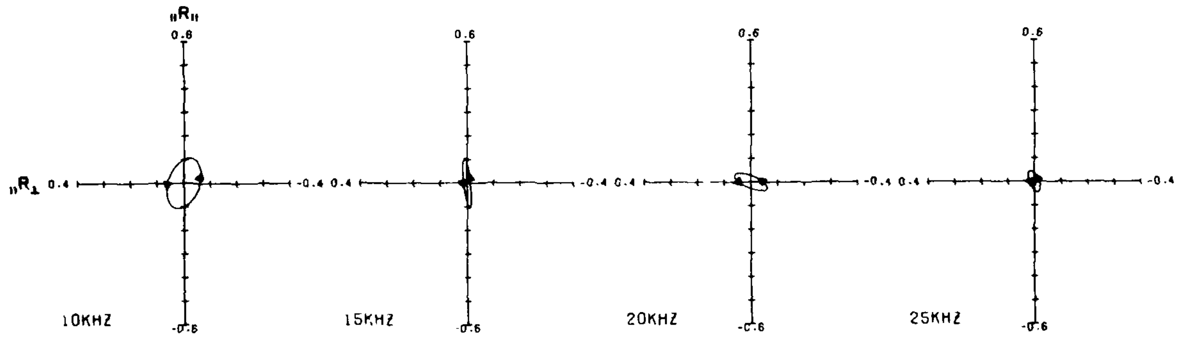
AD-A103 945 ROME AIR DEVELOPMENT CENTER GRIFFISS AFB NY F/G 20/14
EFFECTS OF ENERGETIC PARTICLE EVENTS ON VLF/LF PROPAGATION PARA--ETC(U)
MAR 81 J P TURTLE, J E RASMUSSEN
UNCLASSIFIED RADC-TR-81-82 NL

2 of 2
AD A
103945





J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 17. VLF/LF Ionospheric Reflectivity Data for 31 May 1978 (DAY 151) Solar Particle Event (Cont)

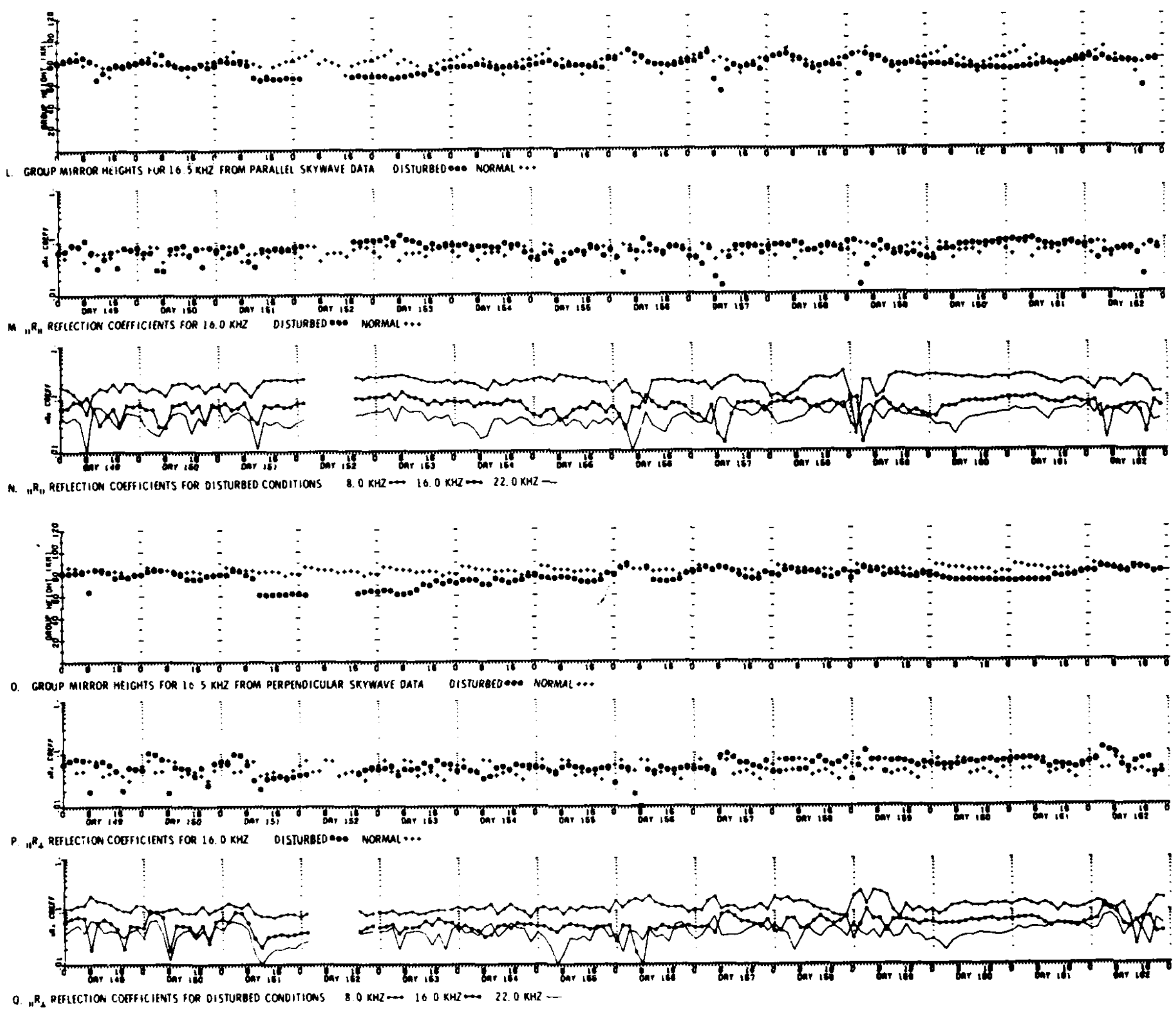


Figure 17. VLF/LF Ionospheric Reflectivity Data for 31 May 1978 (DAY 151) Solar Particle Event (Cont)

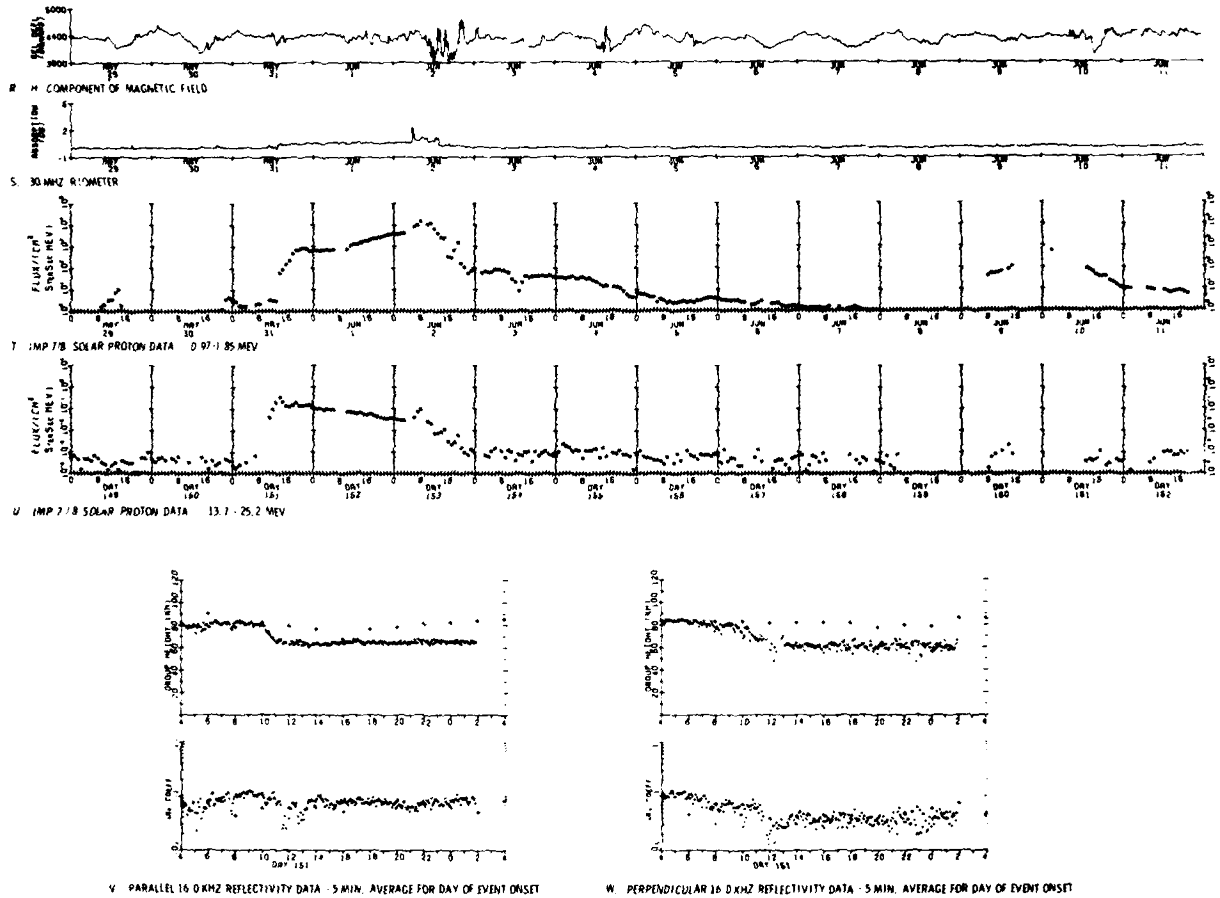


Figure 17. VLF/LF Ionospheric Reflectivity Data for 31 May 1978 (DAY 151) Solar Particle Event (Cont)

[illegible]

11 July 1978 Solar Particle Event

Date:	11 July	Day:	192
Report Figure:	18		
Related Solar Flare:		0625 UT	X-ray class: X3
		1058 UT	X15
Start of Ionospheric Disturbance:		About 1000 UT	
Time of Maximum 13-25 MeV Proton Flux:		13 July 0600 UT	
Maximum Flux:		0.2 Particles/cm^2 sec sr MeV	
Length of Particle Event:		7 days	
Lowest 16 kHz Reflection Height:		64 km	
30 MHz Riometer Absorption:		1 dB	
Solar Zenith Angle Range:		53° - 81°	
Illumination Conditions:		Daytime	

This was a daytime event. Unlike most events in this report the particle flux seen in parts L and U showed a slow rise to maximum level requiring about 2 days. As is often seen in daytime events the [illegible] reflection coefficients (parts N and Q) were stronger during the time of particle maximum than before the disturbance onset. This maximum was followed by a period of several days with fairly steady reflection coefficients. Towards the end of the event the 22 kHz reflection coefficients gradually dropped to a low level before returning to normal. As with other daytime events the reflection heights showed a decrease followed by a gradual recovery with very little diurnal variation.

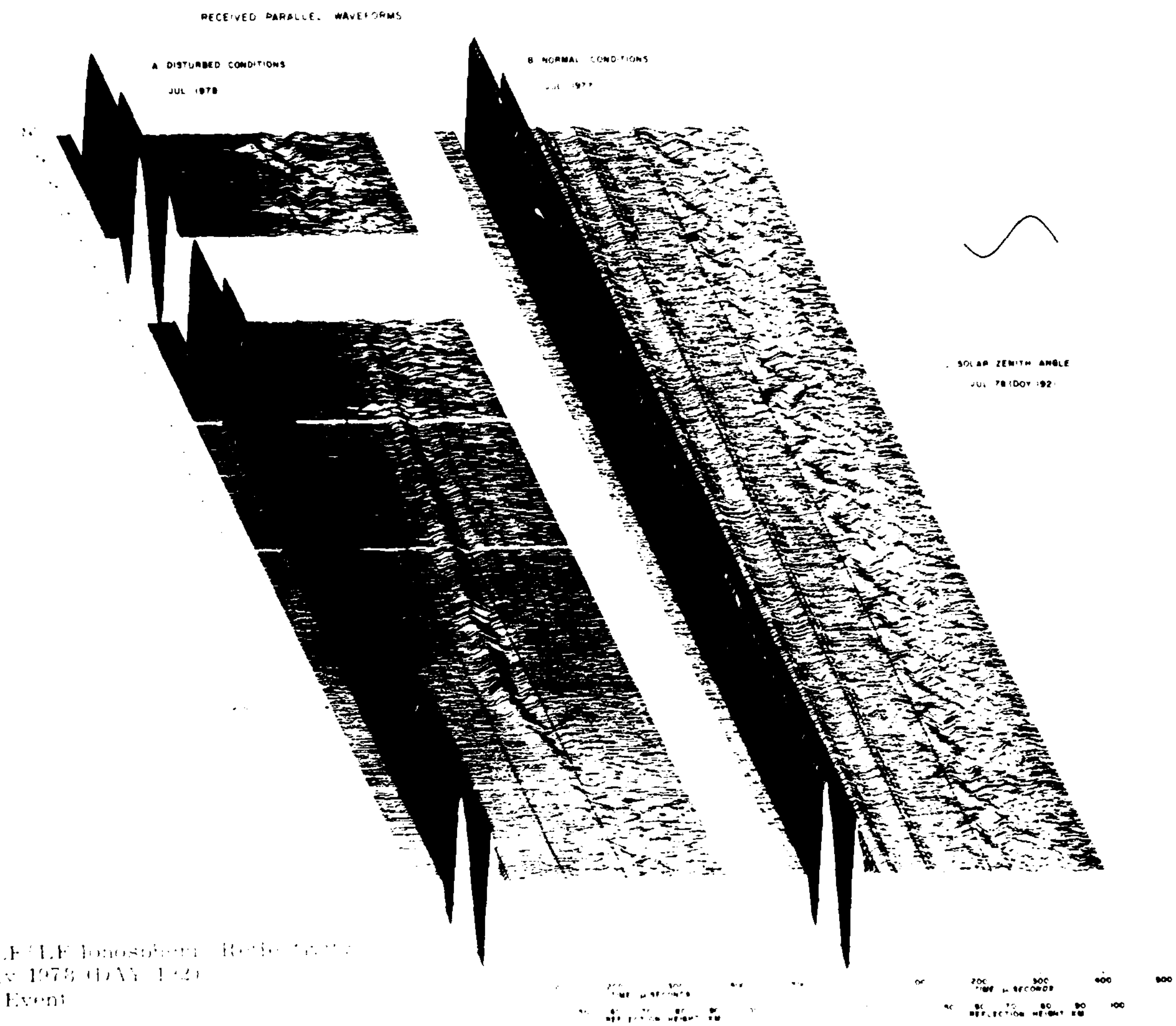


Figure 18. VLF/LF Ionospheric Reflection Data for 11 July 1978 (DAY 192) Solar Particle Event

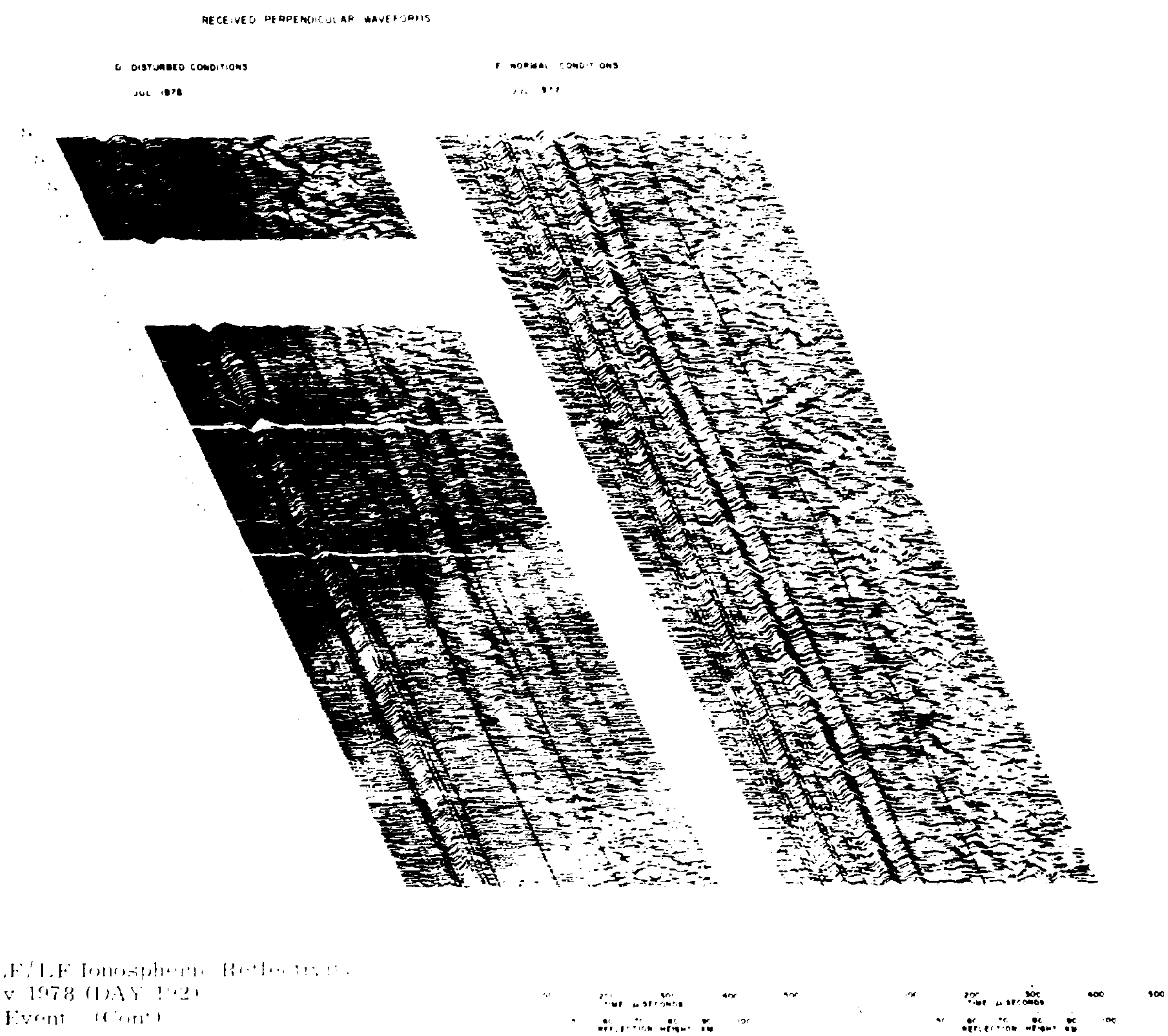


Figure 18. VLF/LF Ionospheric Reflectivity Data for 11 July 1978 (DAY 192) Solar Particle Event (Con't)

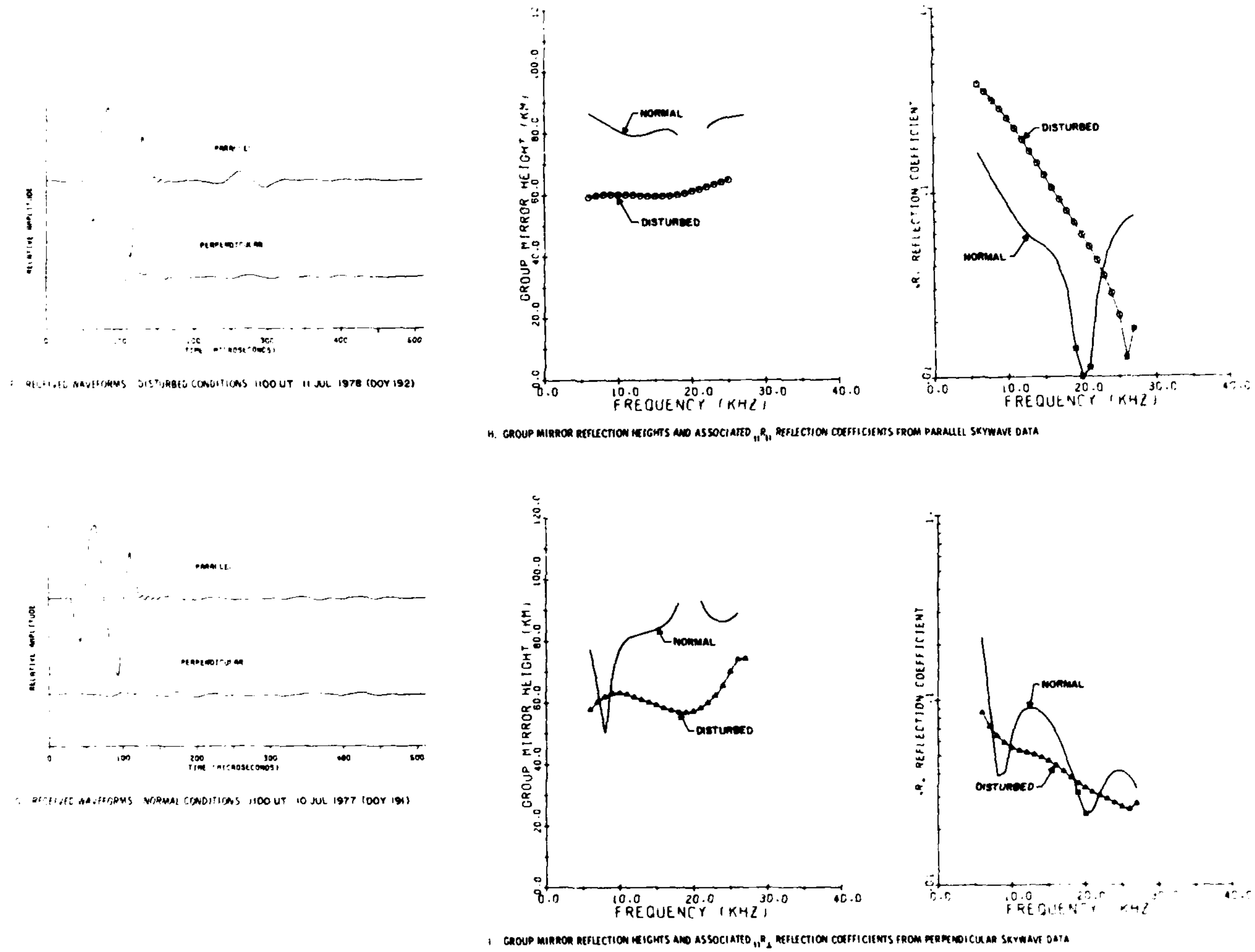
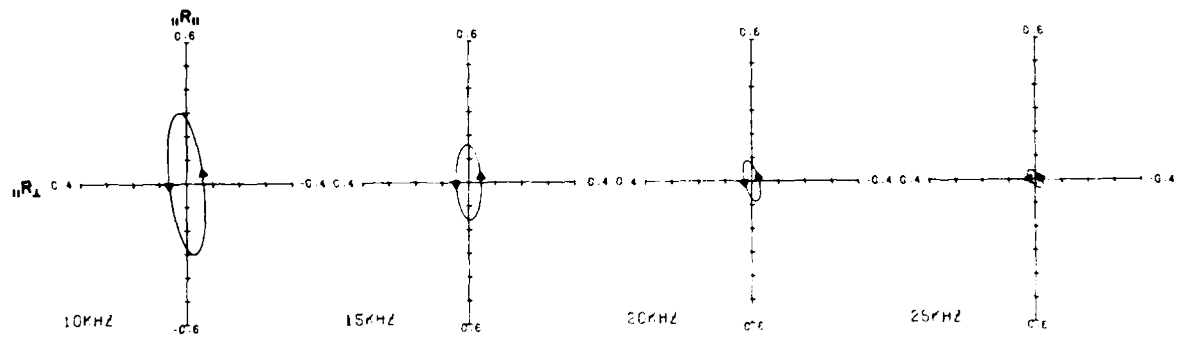
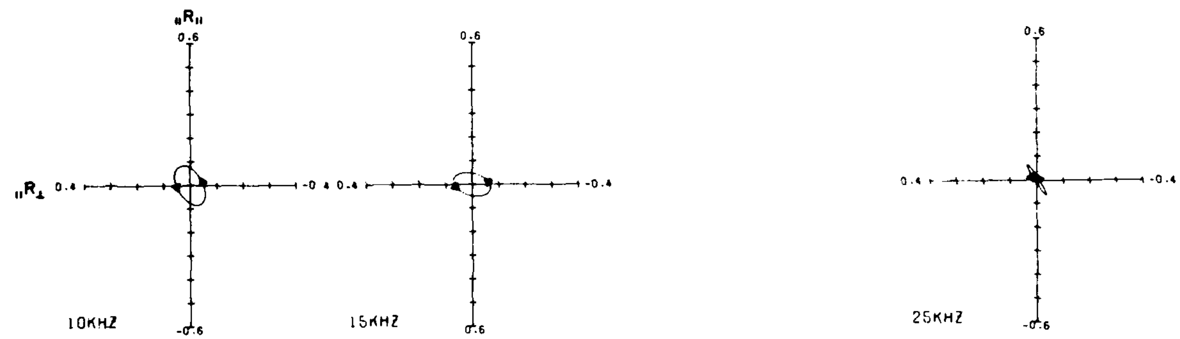


Figure 18. VLF/LF Ionospheric Reflectivity Data for 11 July 1978 (DAY 192) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 18. VLF/LF Ionospheric Reflectivity Data for 11 July 1978 (DAY 192) Solar Particle Event (Cont)

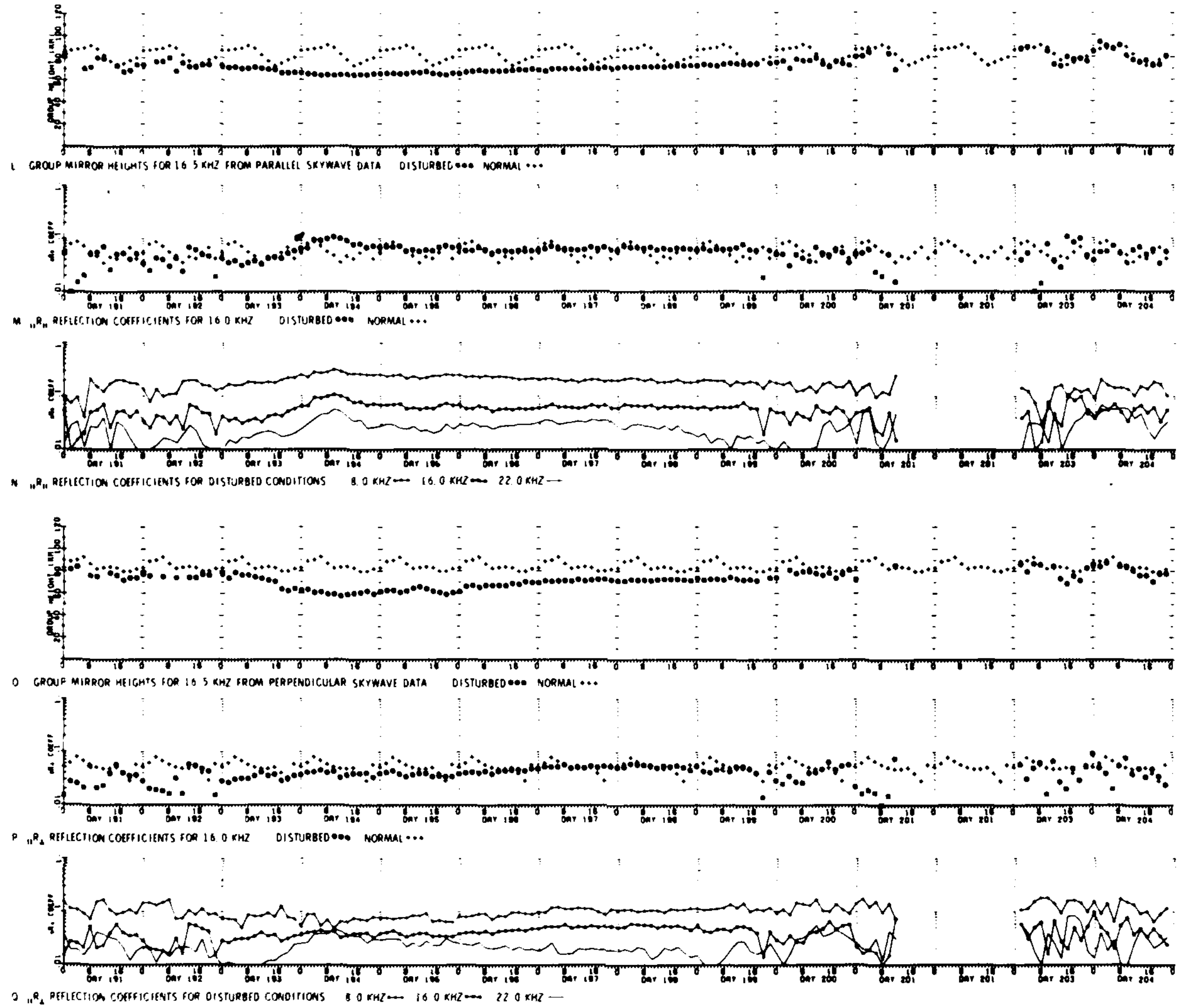


Figure 18. VLF/LF Ionospheric Reflectivity Data for 11 July 1978 (DAY 192) Solar Particle Event (Cont)

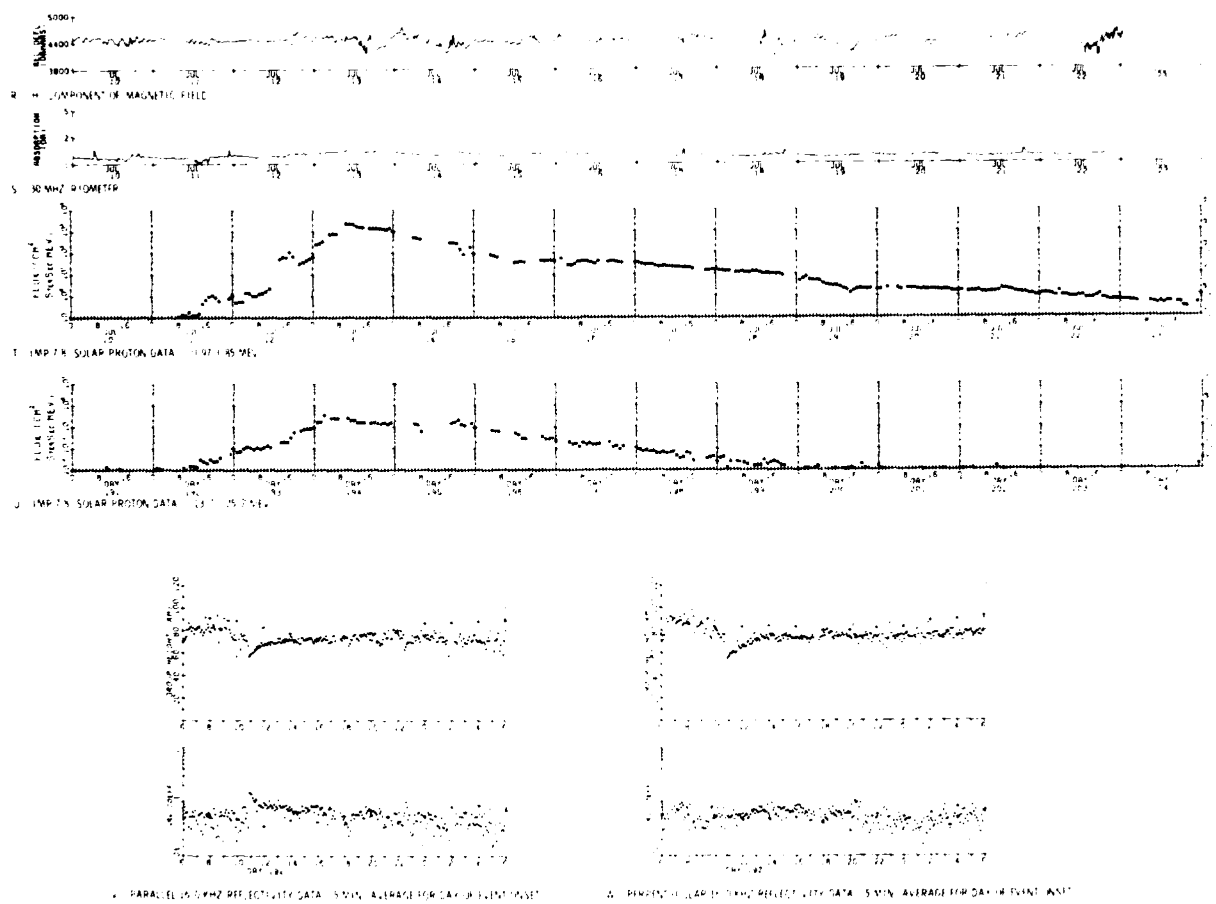


Figure 18. VLF/LF Ionospheric Reflectivity Data for 11 July 1978 (DAY 192) Solar Particle Event (Con't)

[illegible]

8 September 1978 Solar Particle Event

Date:	8 September	Day:	251
Report Figure:	19		
Related Solar Flare:		No data	X-ray class:
Start of Ionospheric Disturbance:		0200 UT	
Time of Maximum 13-25 MeV Proton Flux:		0600 UT	
Maximum Flux:		0.18 particles/cm^2 sec sr MeV	
Length of Particle Event:		3 days	
Lowest 16 kHz Reflection Height:		63 km	
30 MHz Riometer Absorption:		< 0.5 dB	
Solar Zenith Angle Range:		69° - 97°	
Illumination Conditions:		Day-Night	

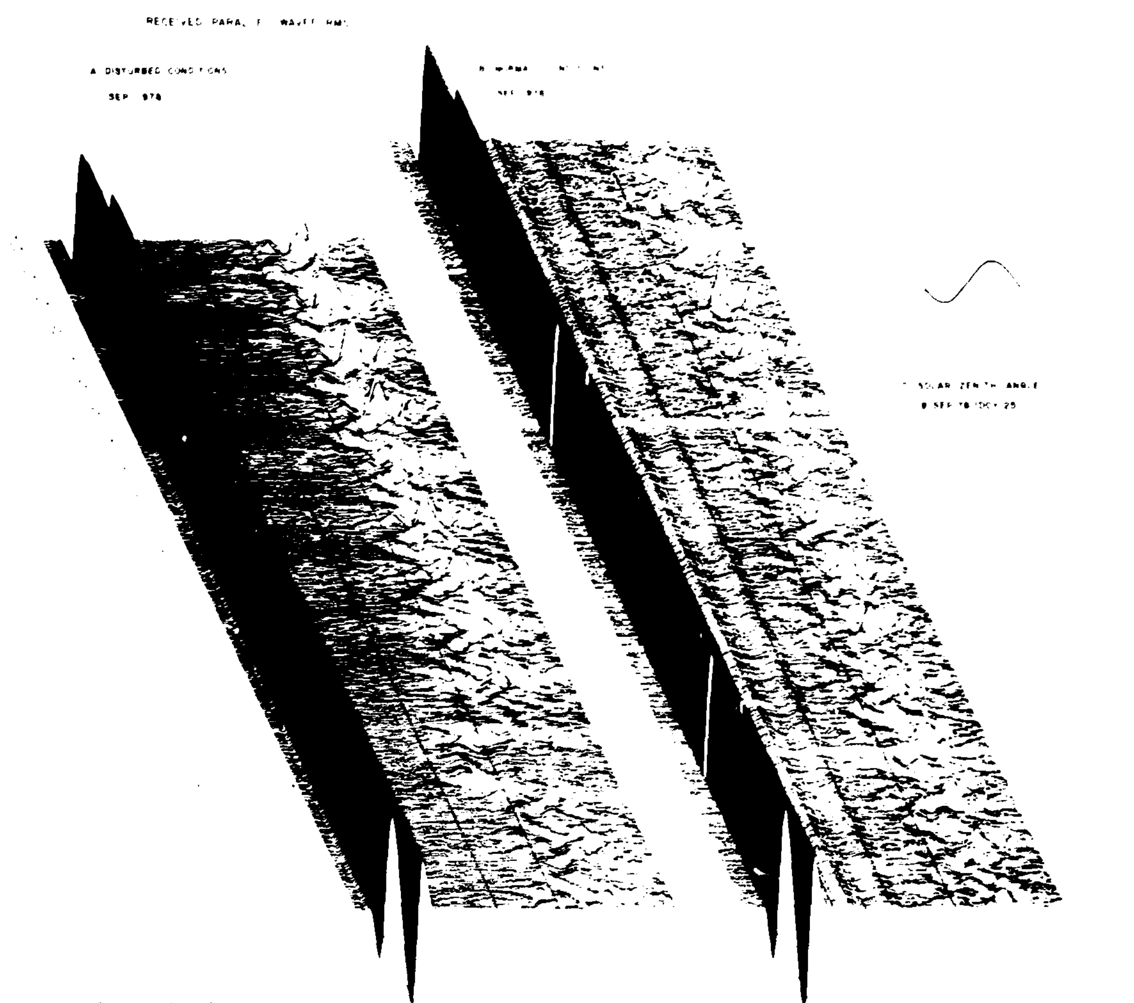


Figure 19. VLF/LF Ionosphere [illegible]
Data for 8 September 1978 (DAY [illegible])
Solar Particle Event

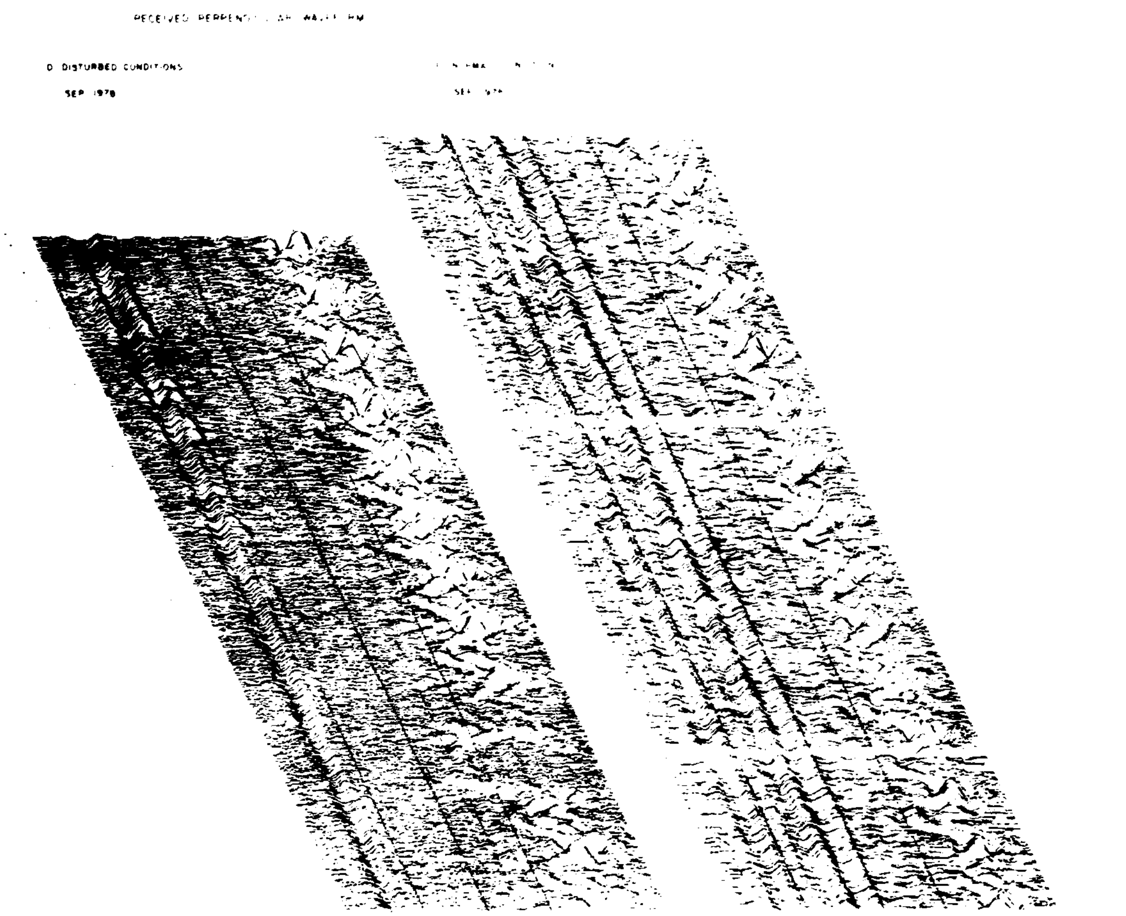
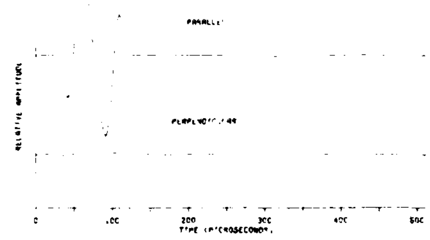
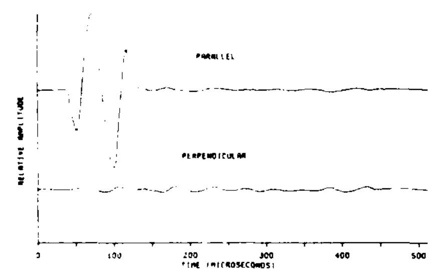


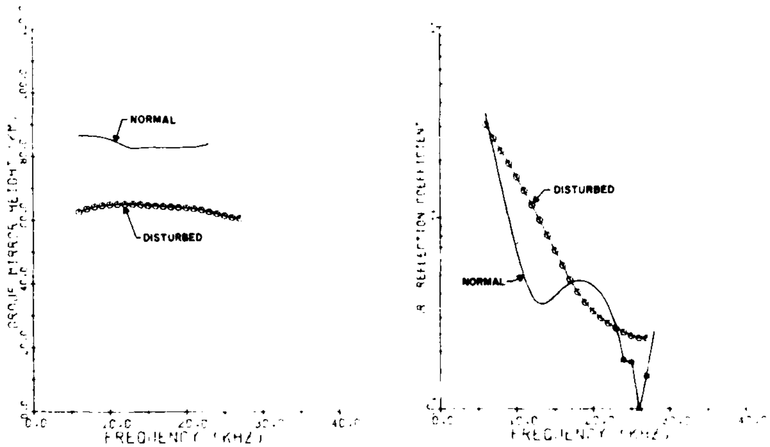
Figure [illegible]. VLF-LF Ionospheric Reflection
Data for 8 September 1978 (DAY 251)
Solar Particle Event (Cont)



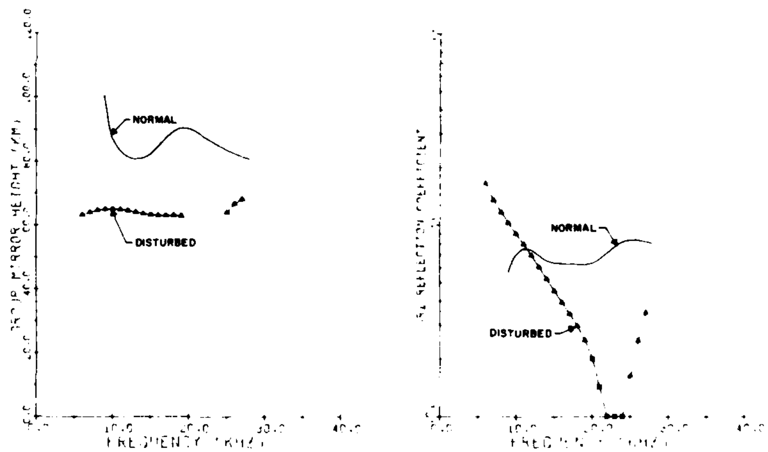
F. RECEIVED WAVEFORMS DISTURBED CONDITIONS 1100 UT 8 SEP 1978 (DOY 251)



G. RECEIVED WAVEFORMS NORMAL CONDITIONS 1100 UT 4 SEP 1976 (DOY 248)

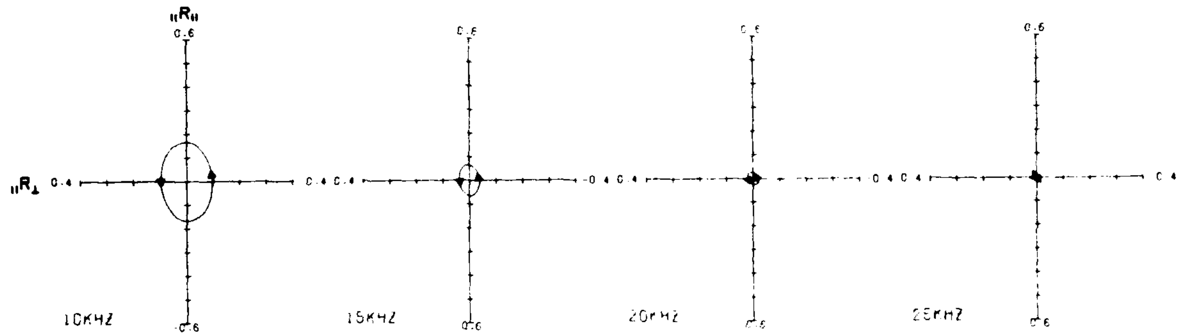


H. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA

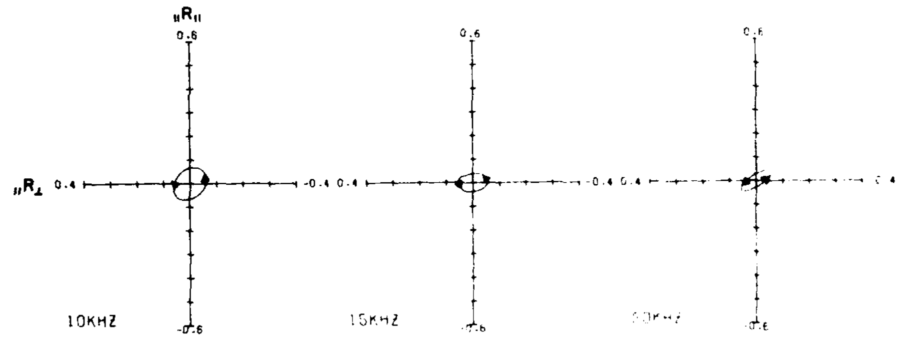


I. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 19. VLF/LF Ionospheric Reflectivity Data for 8 September 1978 (DAY 251) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES NORMAL CONDITIONS

Figure 19. VLF/LF Ionospheric Reflectivity Data for 8 September 1978 (DAY 251) Solar Particle Event (Cont)

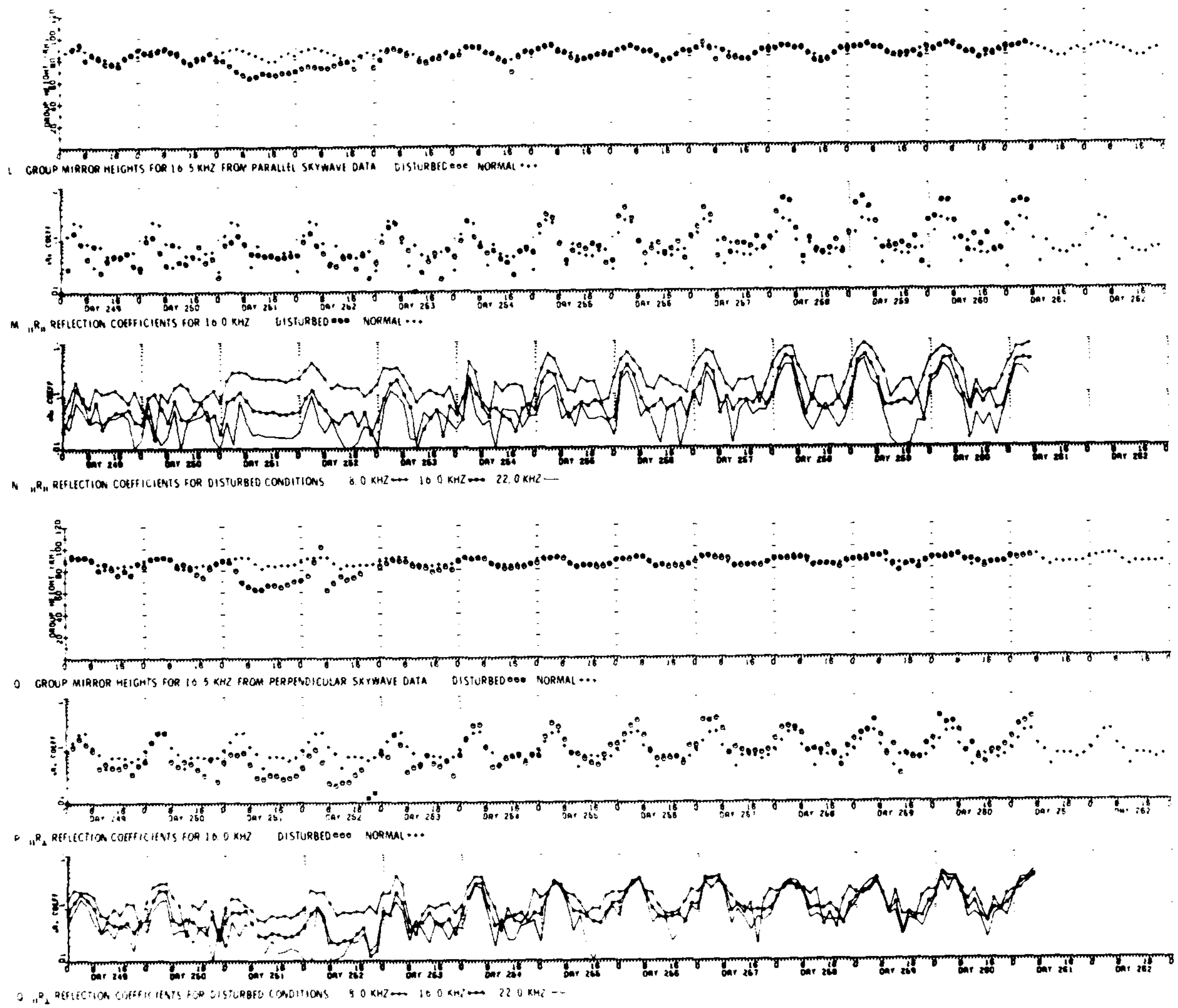


Figure 19. VLF/LF Ionospheric Reflectivity Data for 8 September 1978 (DAY 251) Solar Particle Event (Cont

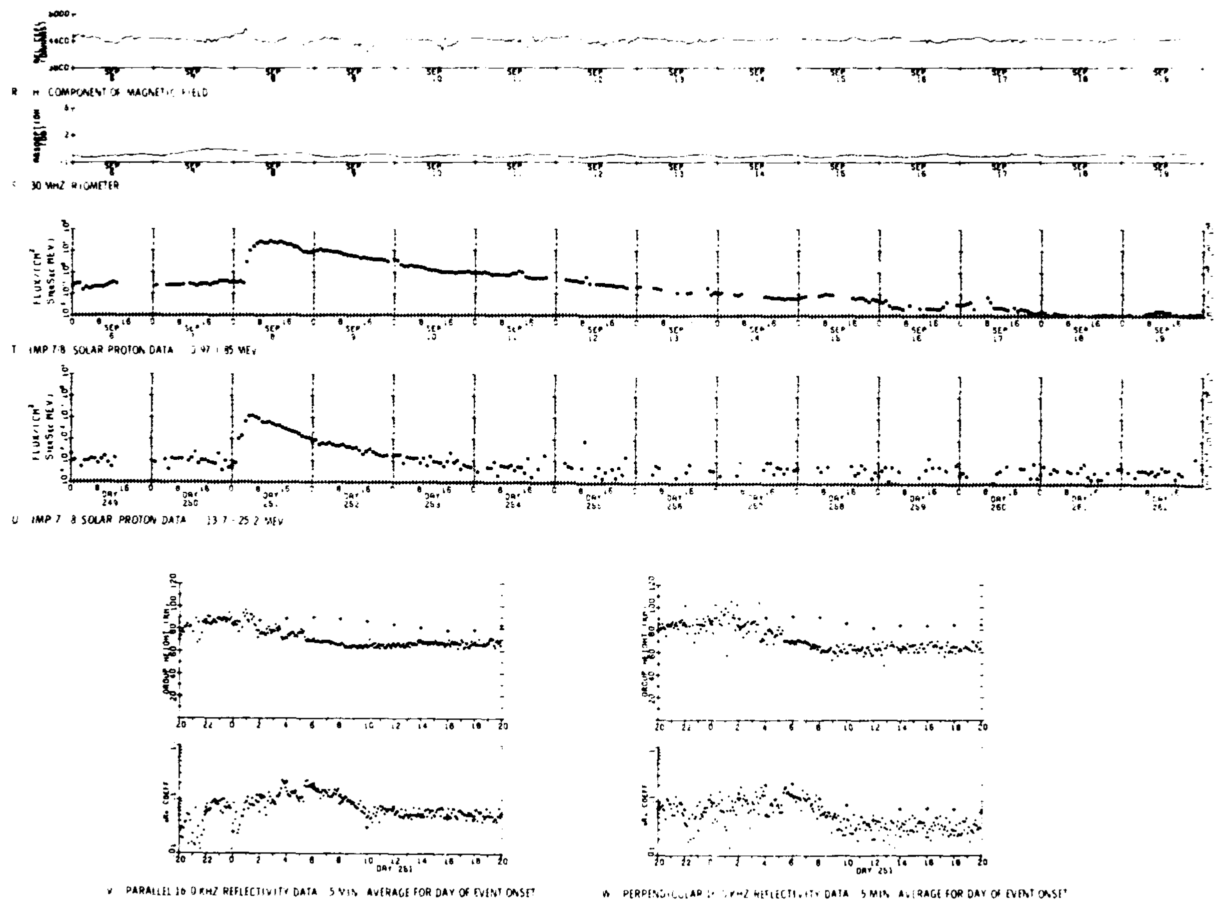


Figure 19. VLF/LF Ionospheric Reflectivity Data for 8 September 1978 (DAY 251) Solar Particle Event (Cont)

[illegible]

23 September 1978 Solar Particle Event

Date: 23 September	Day: 266
Report Figure: 20	
Related Solar Flare:	1021 UT X-ray class: X1
Start of Ionospheric Disturbance:	1030 UT
Time of Maximum 13-25 MeV Proton Flux:	24 September 1500 UT
Maximum Flux:	100 particles/cm^2 sec sr MeV
Length of Particle Event:	12 days
Lowest 16 kHz Reflection Height:	51 km
30 MHz Riometer Absorption:	10 dB
Solar Zenith Angle Range:	77° - 103°
Illumination Conditions:	Day-Night

This was the strongest energetic particle event which has occurred since the VLF/LF ionosounding program began in 1974. Record low reflection heights were recorded; 51 km for the 16 kHz $\parallel$ polarization and 47 km for the $\perp$ component. During the event the reflection height curves showed a diurnal variation, the amplitude of this variation increased as the particle flux decreased. The nighttime reflection heights recovered towards normal more rapidly than the daytime (sunlit) reflection heights. The reflection coefficients showed less diurnal amplitude variation during the event than before or afterwards. The sharp nulls seen in the reflection coefficient data (parts N and Q) at about 0900 UT and 0000 UT are caused by the 2-hr average window used in data reduction. A 5-min average plot of the data at these sunrise and sunset times does not show these nulls.

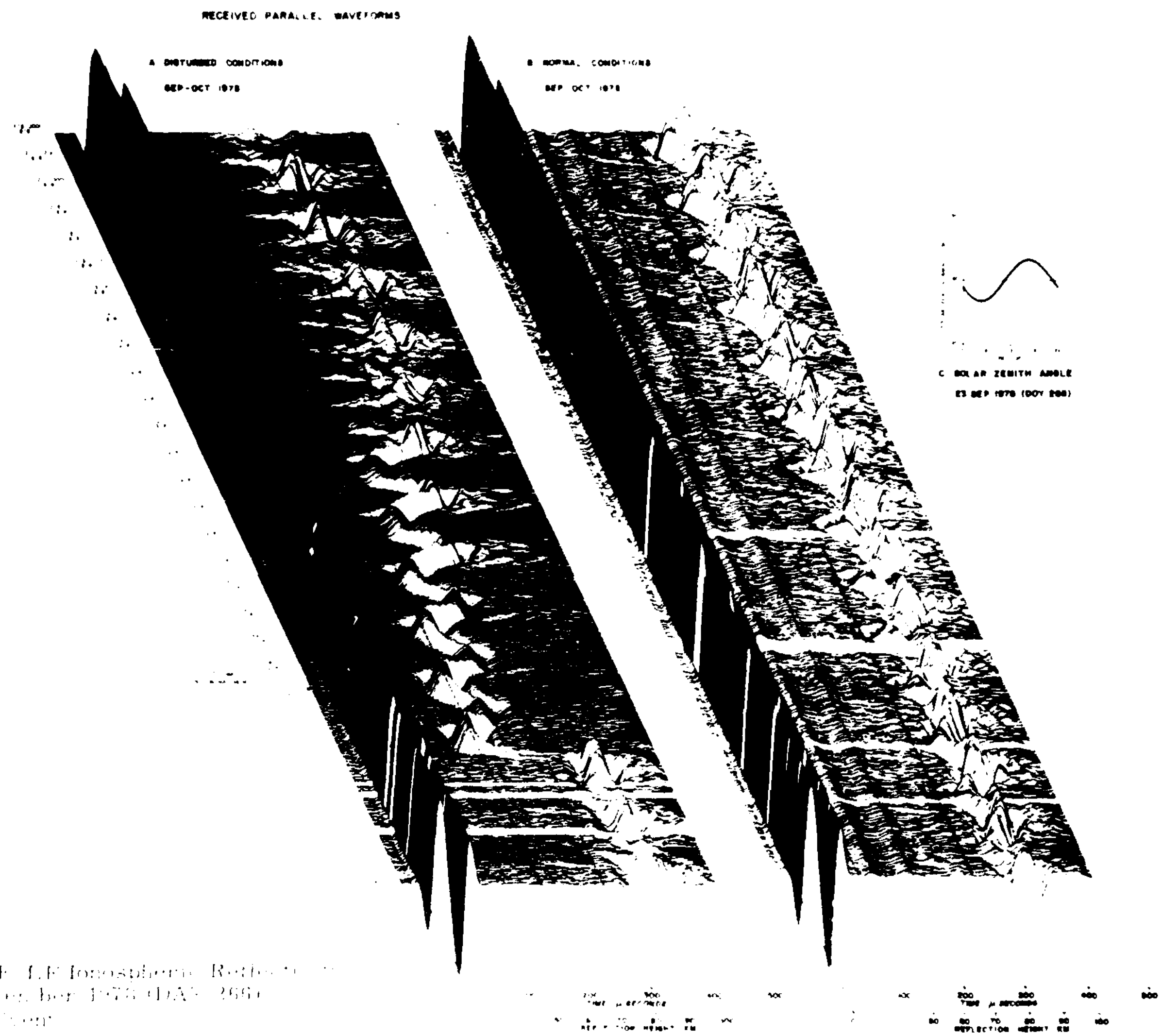


Figure 29. VLF/LF Ionospheric Reflection Data for 23 September 1978 (DAY 266) Solar Particle Event

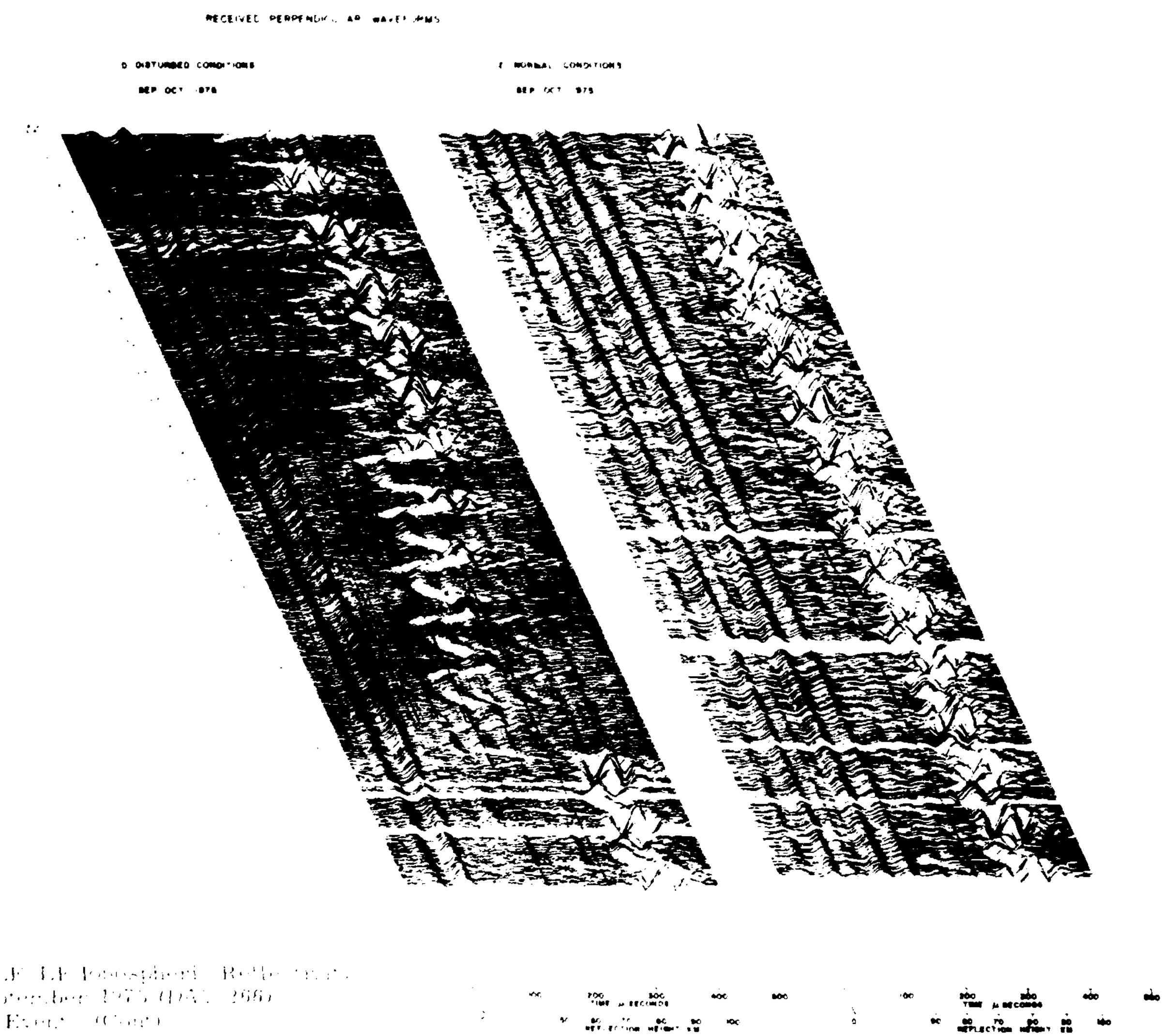


Figure 20. VLF LF Ionospheric Reflection Data for 23 September 1975 (DAY 266) Solar Particle Event (Cont)

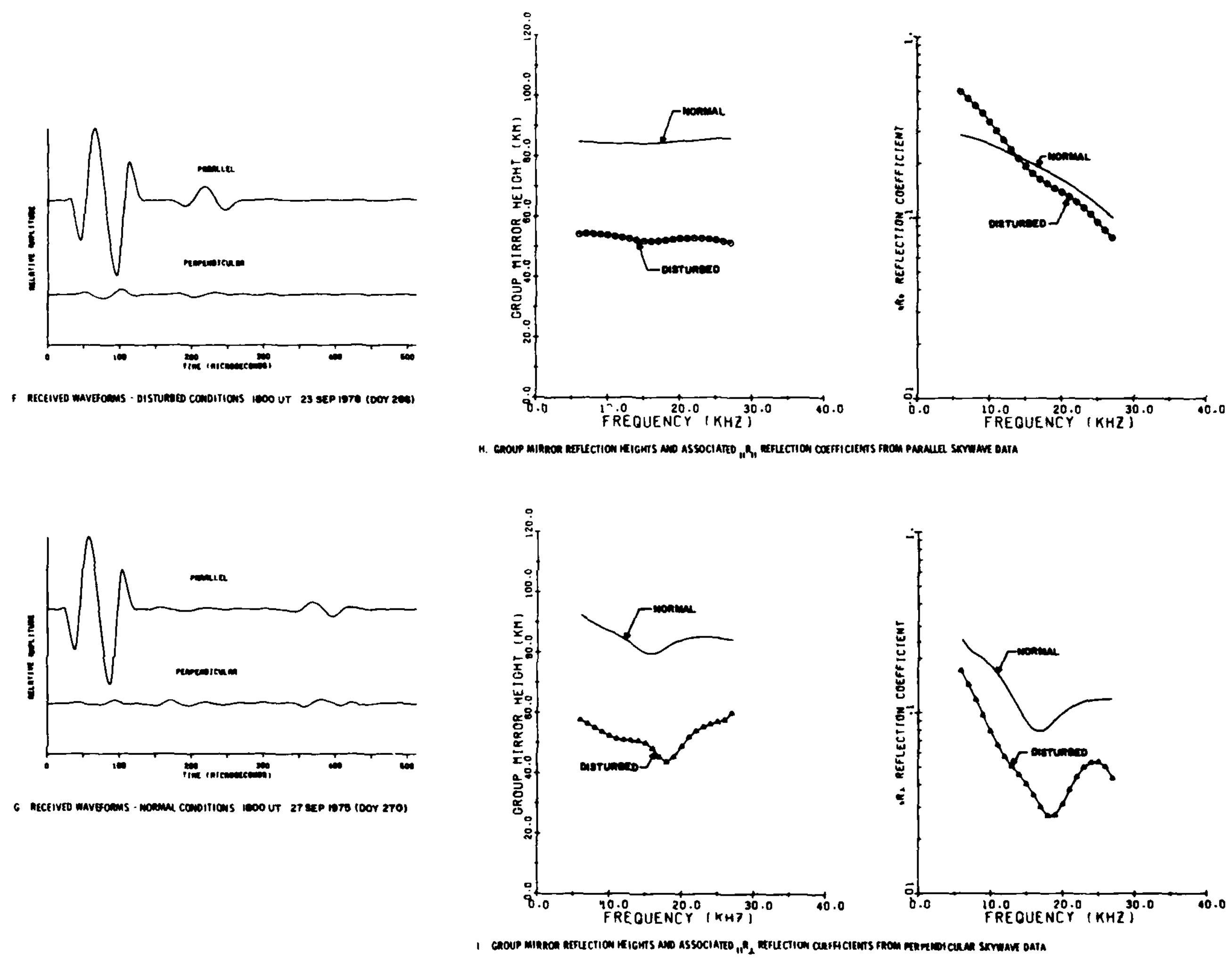
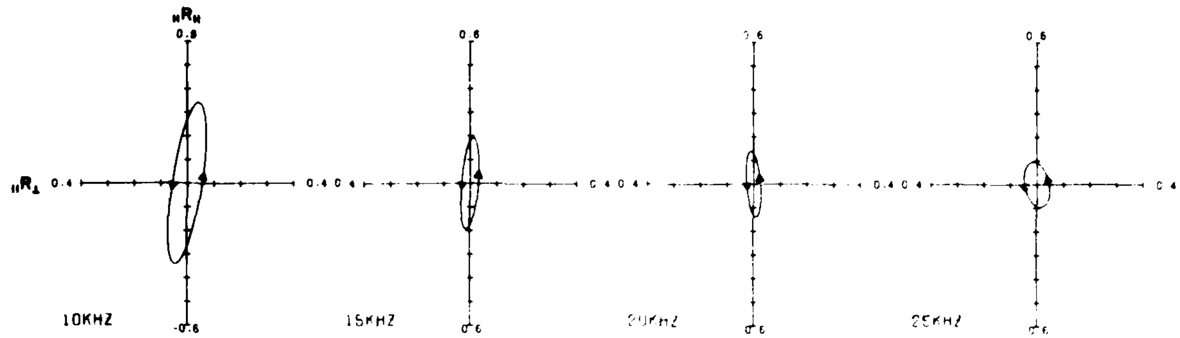
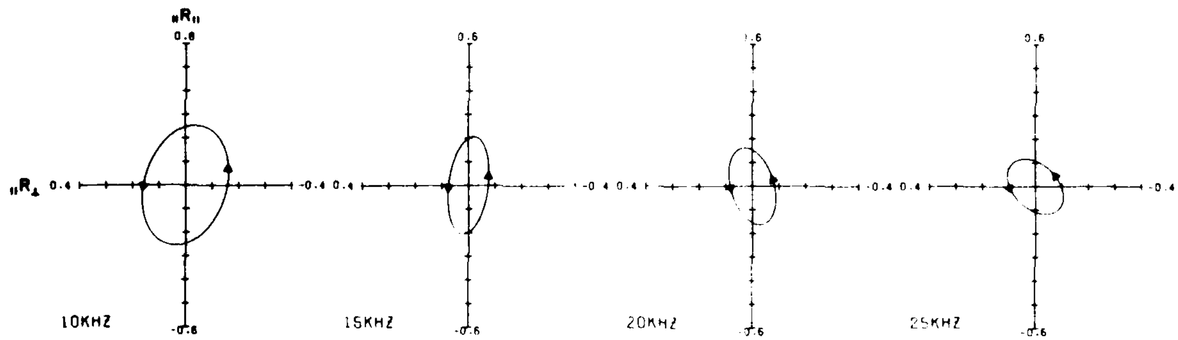


Figure 20. VLF/LF Ionospheric Reflectivity Data for 23 September 1978 (DAY 266) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES · DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES · NORMAL CONDITIONS

Figure 20. VLF/LF Ionospheric Reflectivity Data for 23 September 1978 (DAY 266) Solar Particle Event (Cont)

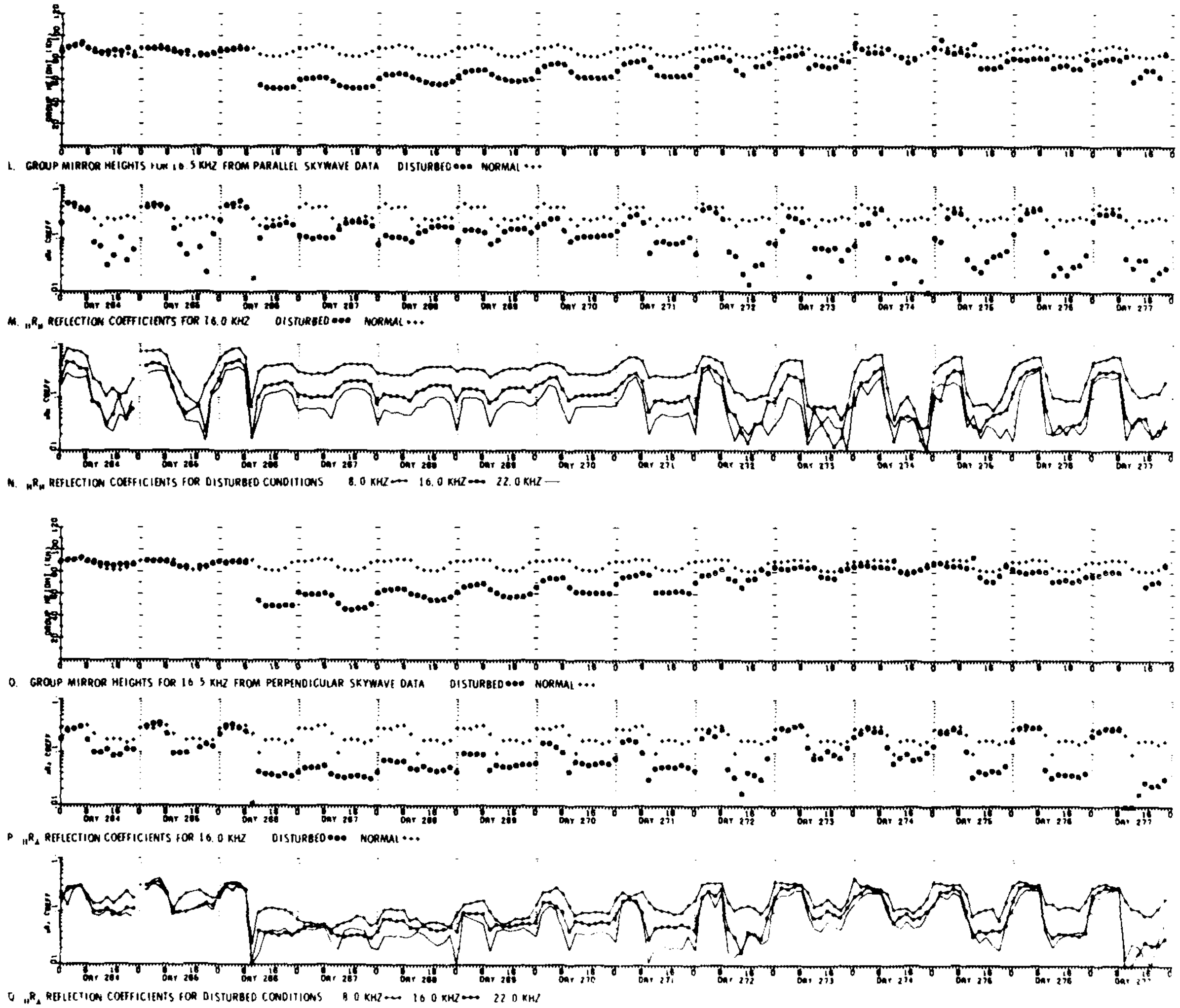


Figure 20. VLF/LF Ionospheric Reflectivity Data for 23 September 1978 (DAY 266) Solar Particle Event (Cont)

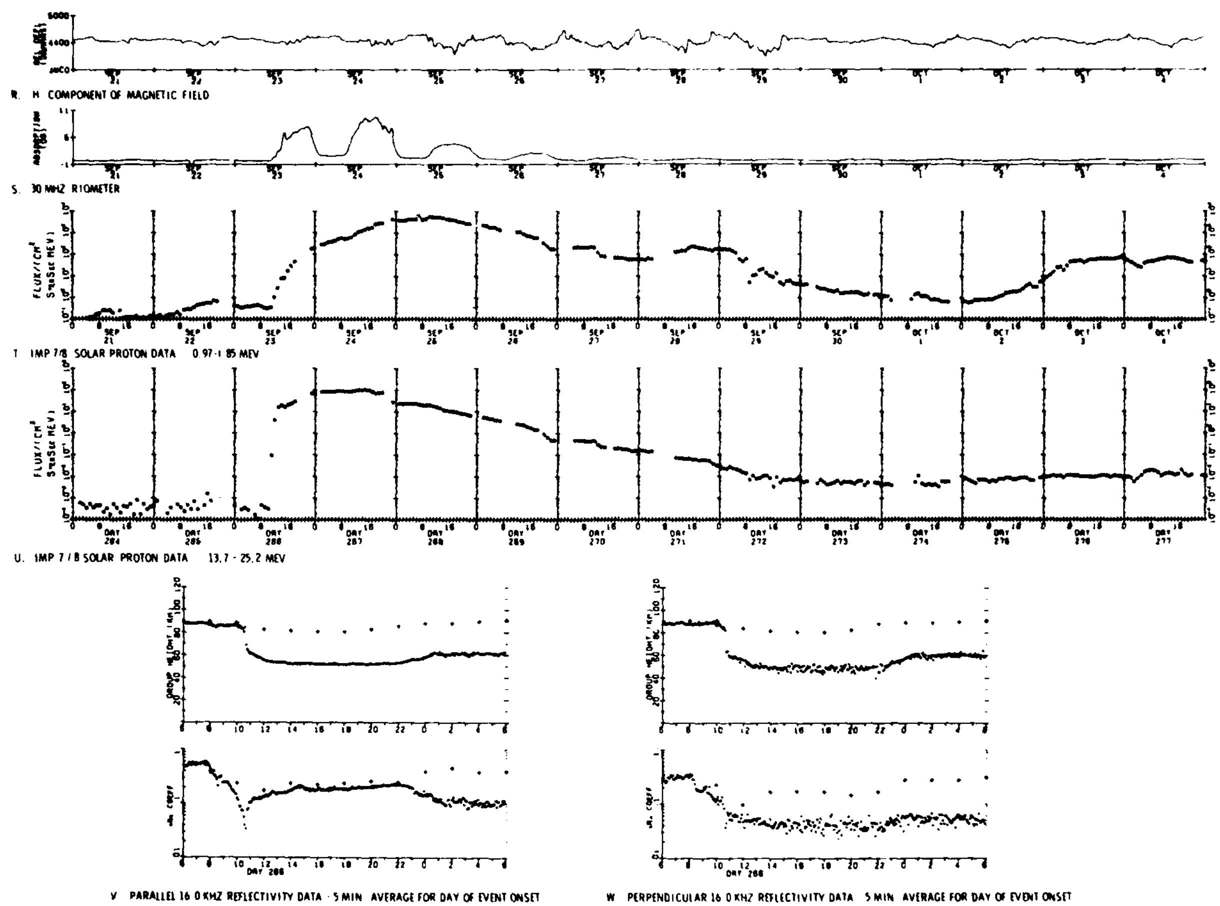


Figure 20. VLF/LF Ionospheric Reflectivity Data for 23 September 1978 (DAY 266) Solar Particle Event (Cont)

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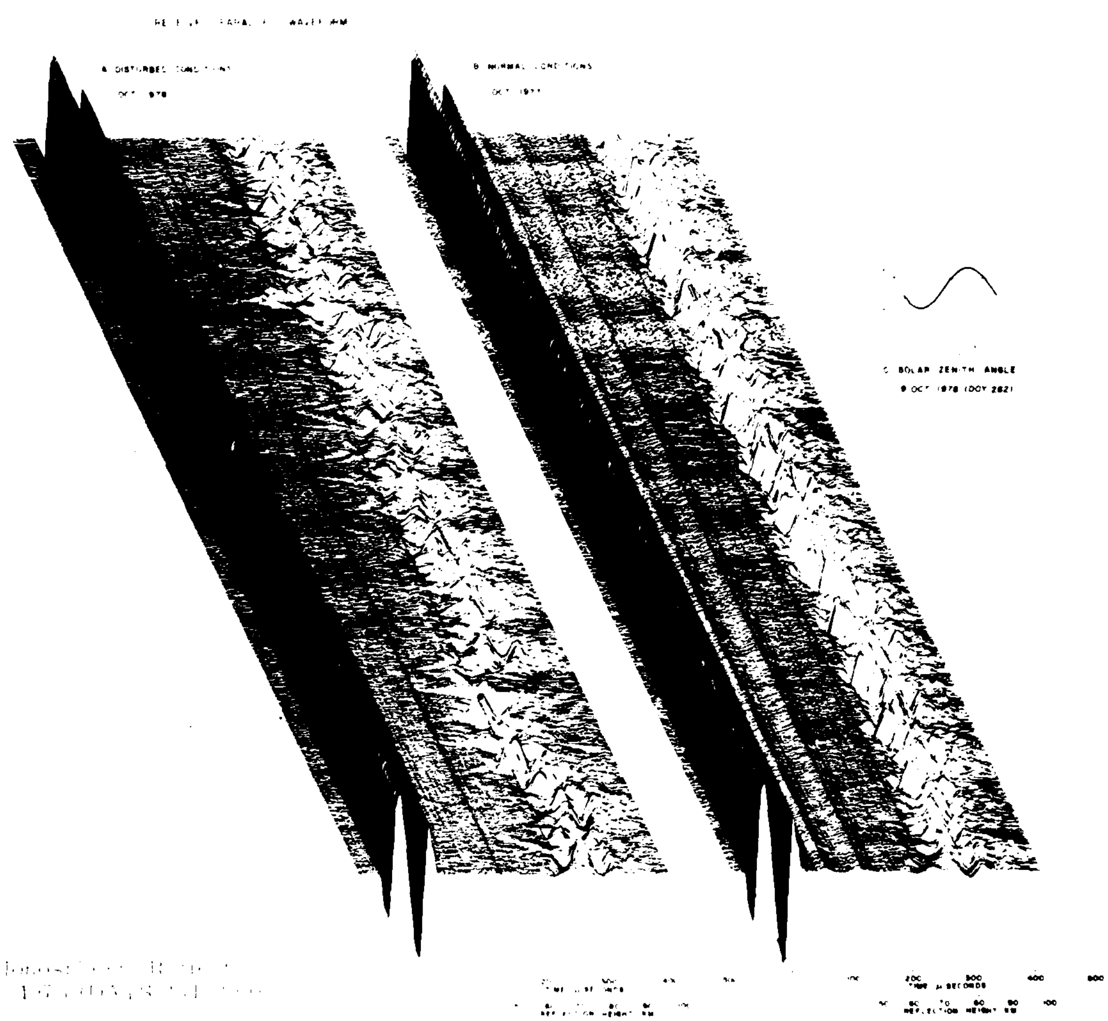
8-17 October 1978 Solar Particle Events

Date: 8 October	Day: 281
Report Figure: 21	
Related Solar Flare:	1937 UT X-ray class: M4
Start of Ionospheric Disturbance:	2215 UT
Time of Maximum 13-25 MeV Proton Flux:	9 October 2300 UT
Maximum Flux:	0.8 particles/cm^2 sec sr MeV
Length of Particle Event:	3 days
Lowest 16 kHz Reflection Height:	65 km
30 MHz Riometer Absorption:	< 0.5 dB
Solar Zenith Angle Range:	81° - 107°
Illumination Conditions:	Day-Night
Subsequent Events:	13 October (DAY 286) Maximum Flux: 0.02 particles 0900 UT 14 October 17 October (DAY 290) Maximum Flux: no data

A series of four energetic particle events occurred during October 1978. The last two occurred on consecutive days (8 and 9 October) and are treated here as one event. The other events which occurred on 13 October and 17 October barely reached threshold. The 8 and 9 October events were day-night disturbances which typically produced enhanced diurnal reflection parameter variations.



A DISTURBED CONDITIONS
B NORMAL CONDITIONS
C SOLAR ZENITH ANGLE
9 OCT 1978 (DOY 282)
TIME μ SECONDS
REFLECTION HEIGHT KM
100
200
300
400
500
70
80
90
100

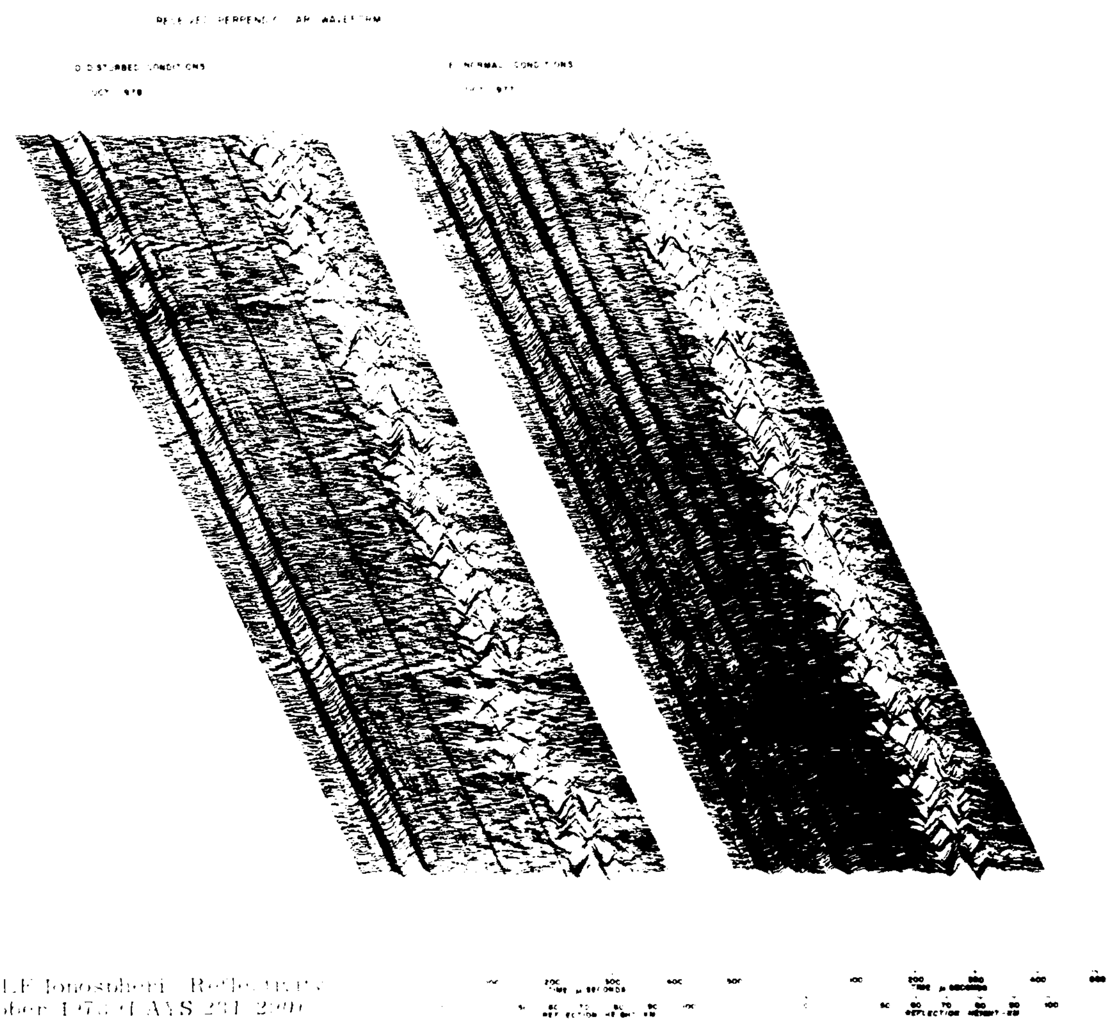
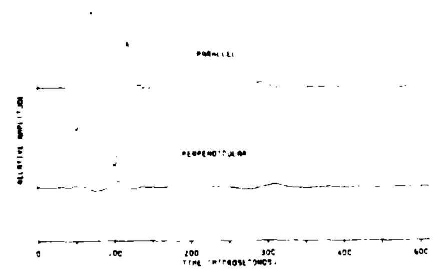
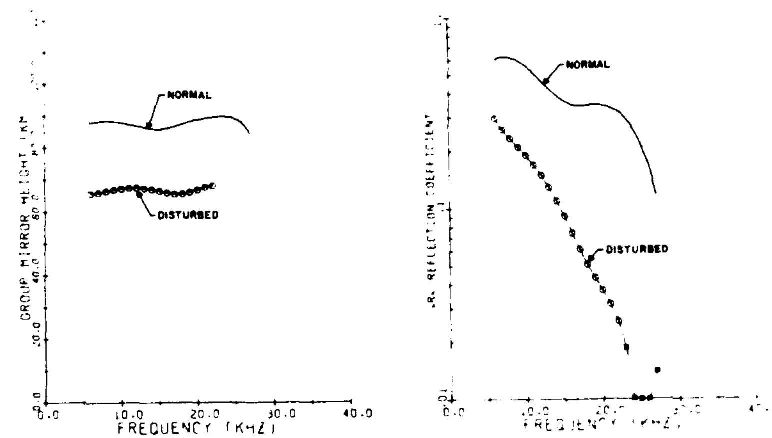


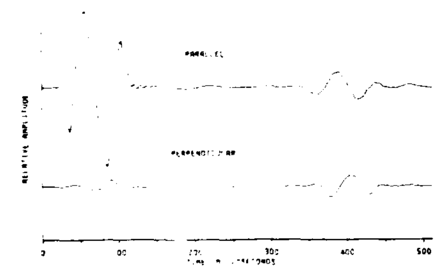
Figure 21. VLF/LF Ionospheric Reflection Data for 17 October 197[illegible] (DAYS 231-2[illegible]) Solar Particle Event (Cont)



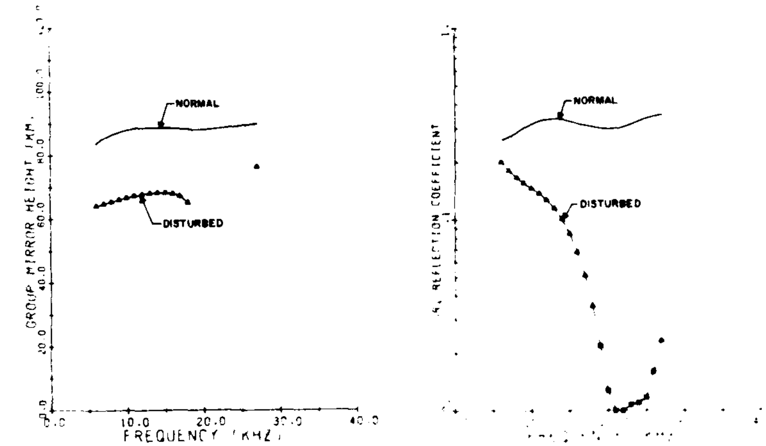
F. RECEIVED WAVEFORMS. DISTURBED CONDITIONS. 1130 UT 9 OCT 1978 (DOY 282)



H. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA

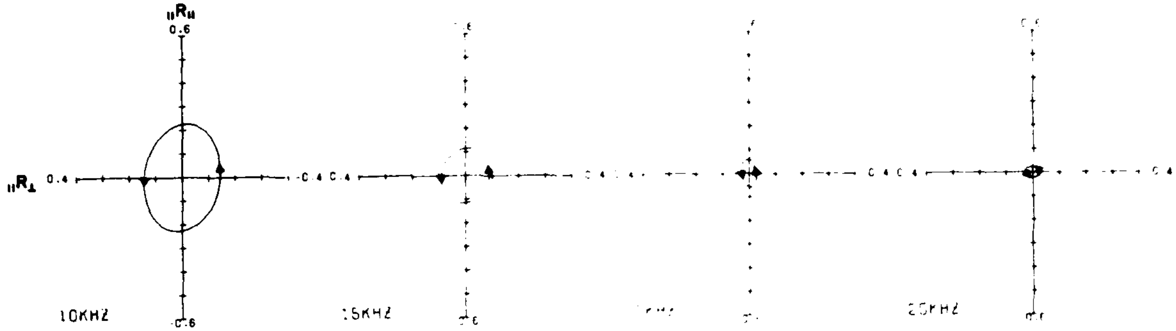


G. RECEIVED WAVEFORMS. NORMAL CONDITIONS. 1130 UT 16 OCT 1977 (DOY 289)

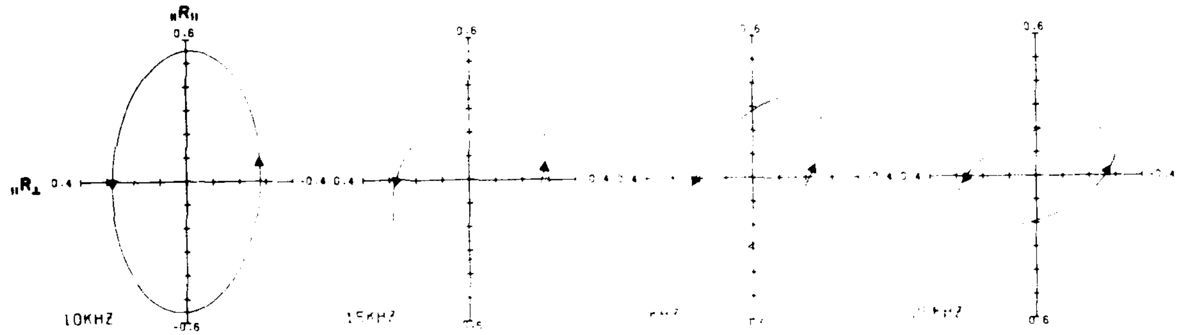


I. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\perp}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 21. VLF/LF Ionospheric Reflectivity Data for 8-17 October 1978 (DAYS 281-290) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 21. VLF/LF Ionospheric Reflectivity Data for 8-17 October 1978 (DAYS 281-290) Solar Particle Event (Cont)

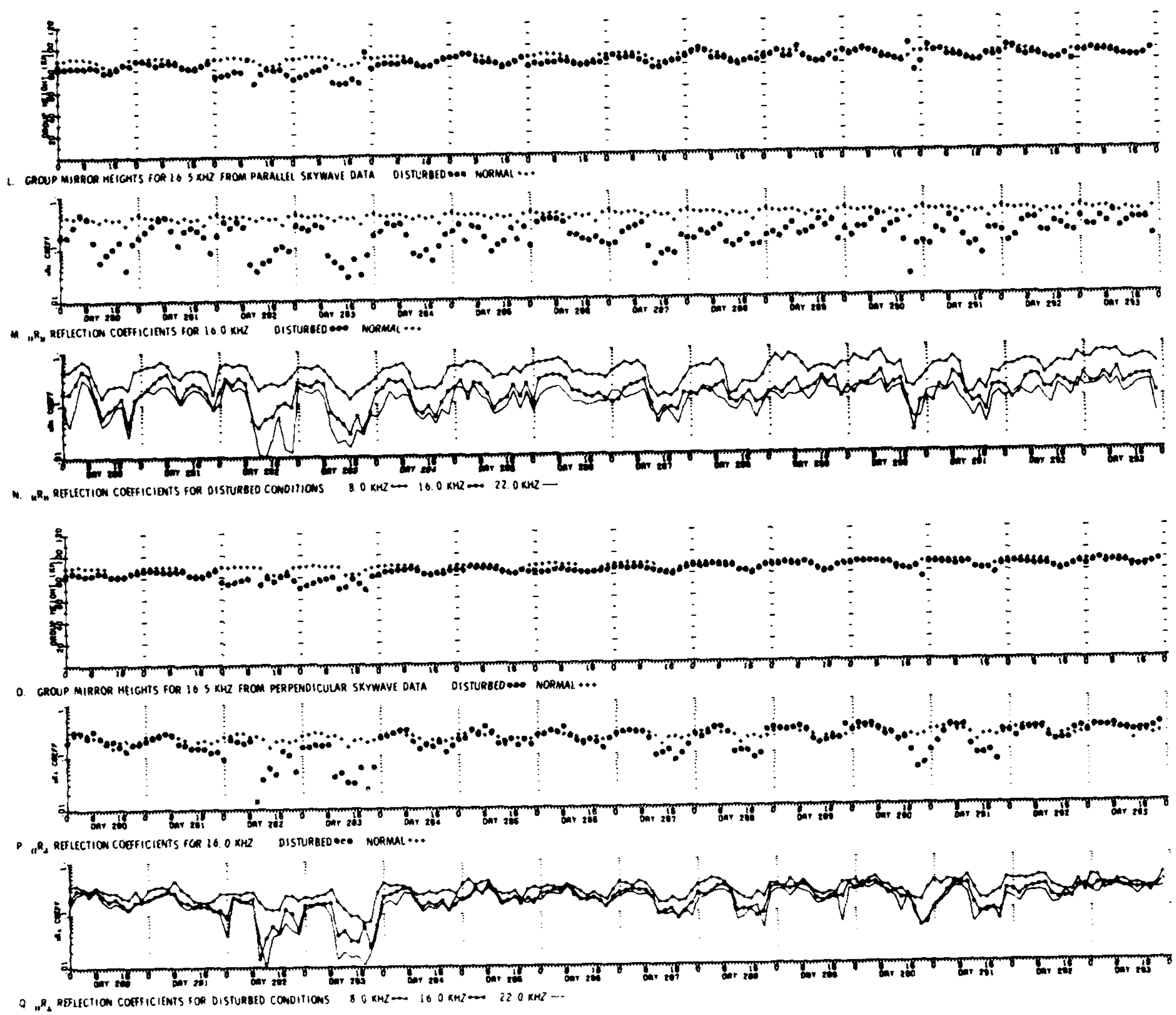


Figure 21. VLF/LF Ionospheric Reflectivity Data for 8-17 October 1978 (DAYS 281-290) Solar Particle Event (Cont)

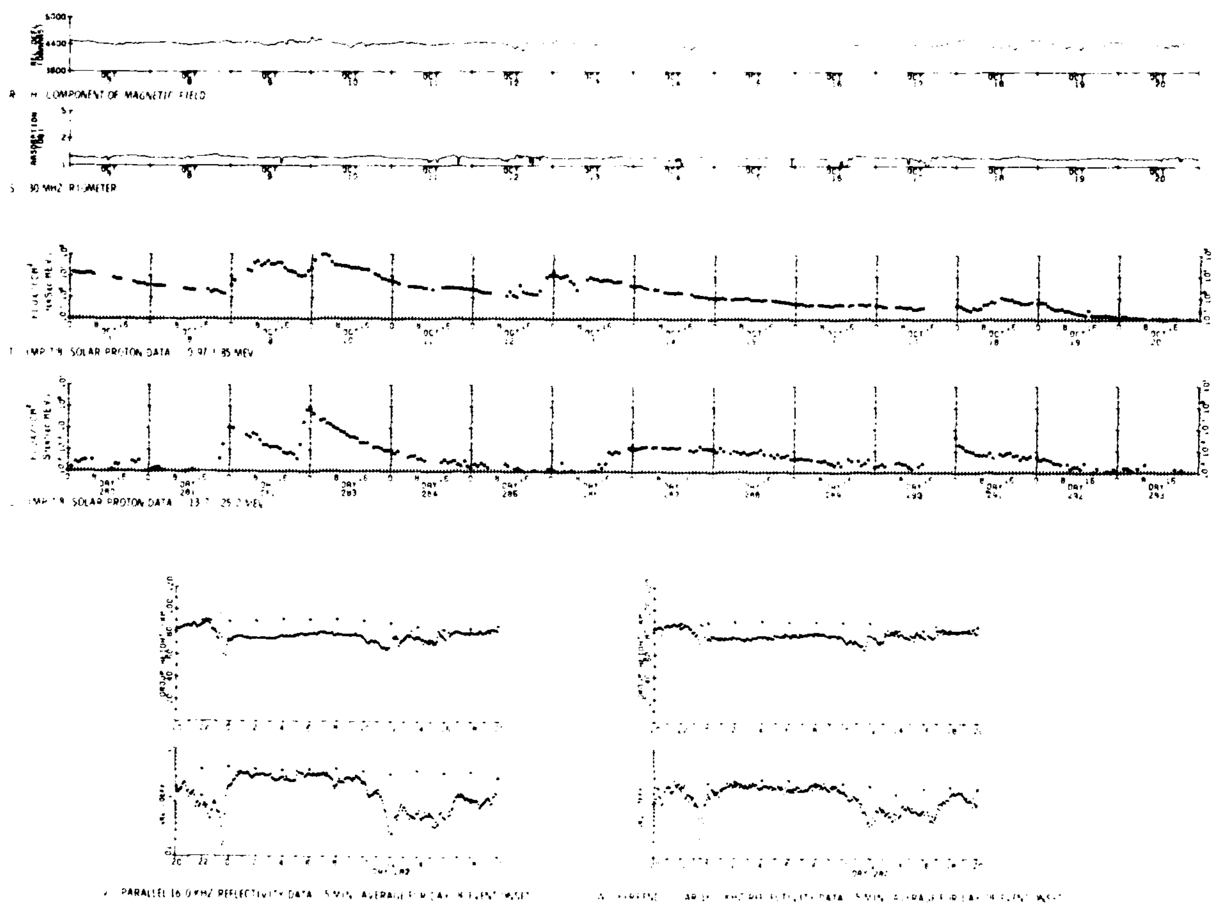


Figure 21. VLF/LF Ionospheric Reflectivity Data for 8-17 October 1978 (DAYS 281-290) Solar Particle Event (Cont)

10 November 1978 Solar Particle Event

Date: 10 November	Day: 314
Report Figure: 22	
Related Solar Flare:	0122 UT X-ray class: M4
Start of Ionospheric Disturbance:	0200 UT
Time of Maximum 13-25 MeV Proton Flux:	11 November 0000 UT
Maximum Flux:	0.3 Particles/cm^2 sec sr MeV
Length of Particle Event:	4 days
Lowest 16 kHz Reflection Height:	65 km
30 MHz Riometer Absorption:	1 dB
Solar Zenith Angle Range	93° - 121°
Illumination Conditions:	Day - Night

This event occurred during the period when under normal conditions there was insufficient daytime solar radiation to produce a diurnal variation in either reflection parameter. However, as was the case in the 13 February event, during the disturbance the combination of particle ionization and varying solar radiation produced a day-night change in both the reflection heights and coefficient (parts L, M, O, and P).

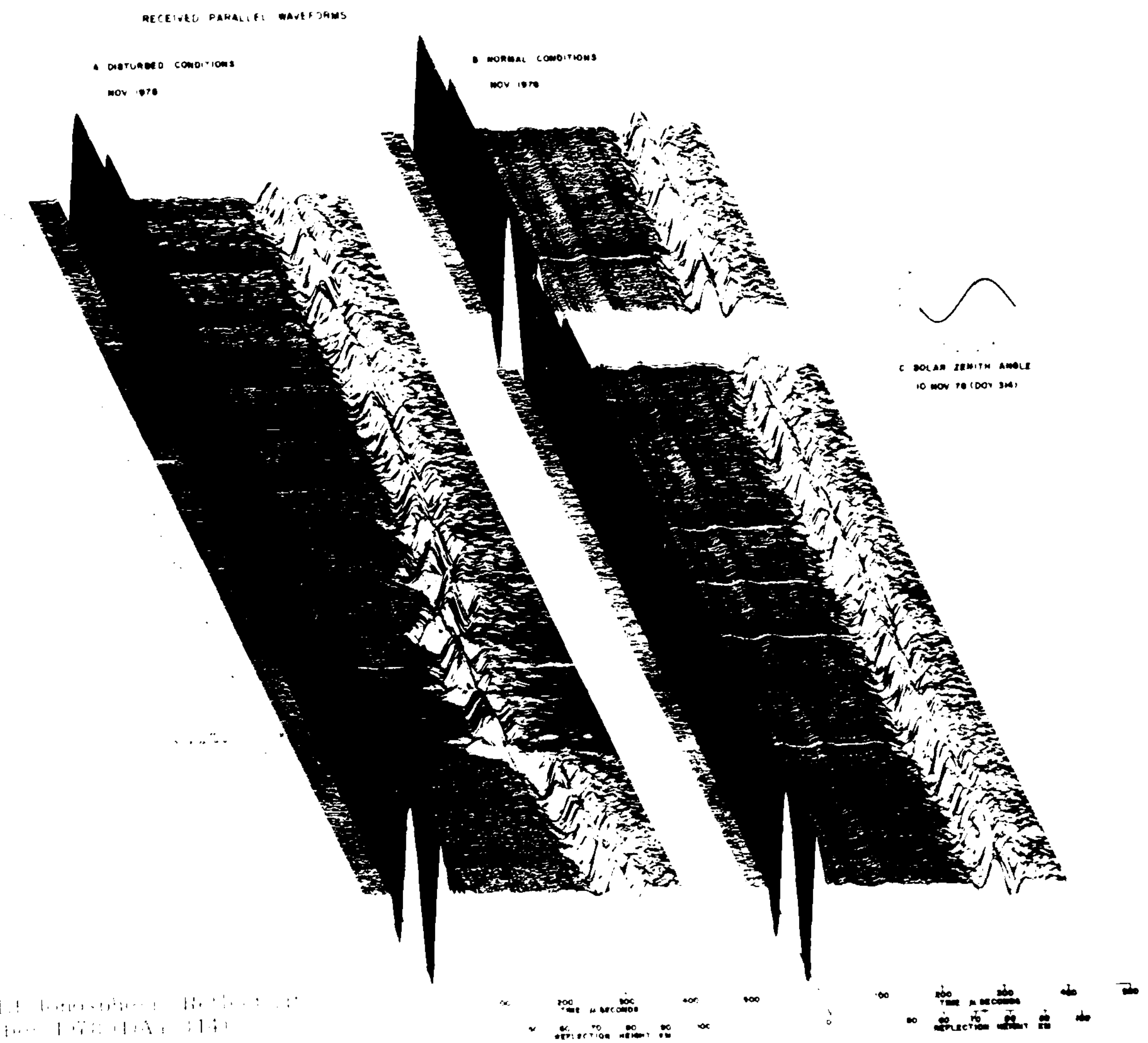


Figure 22. [illegible] Ionospheric Reflection [illegible] 10 November 1978 (DAY 314) [illegible] Part [illegible]

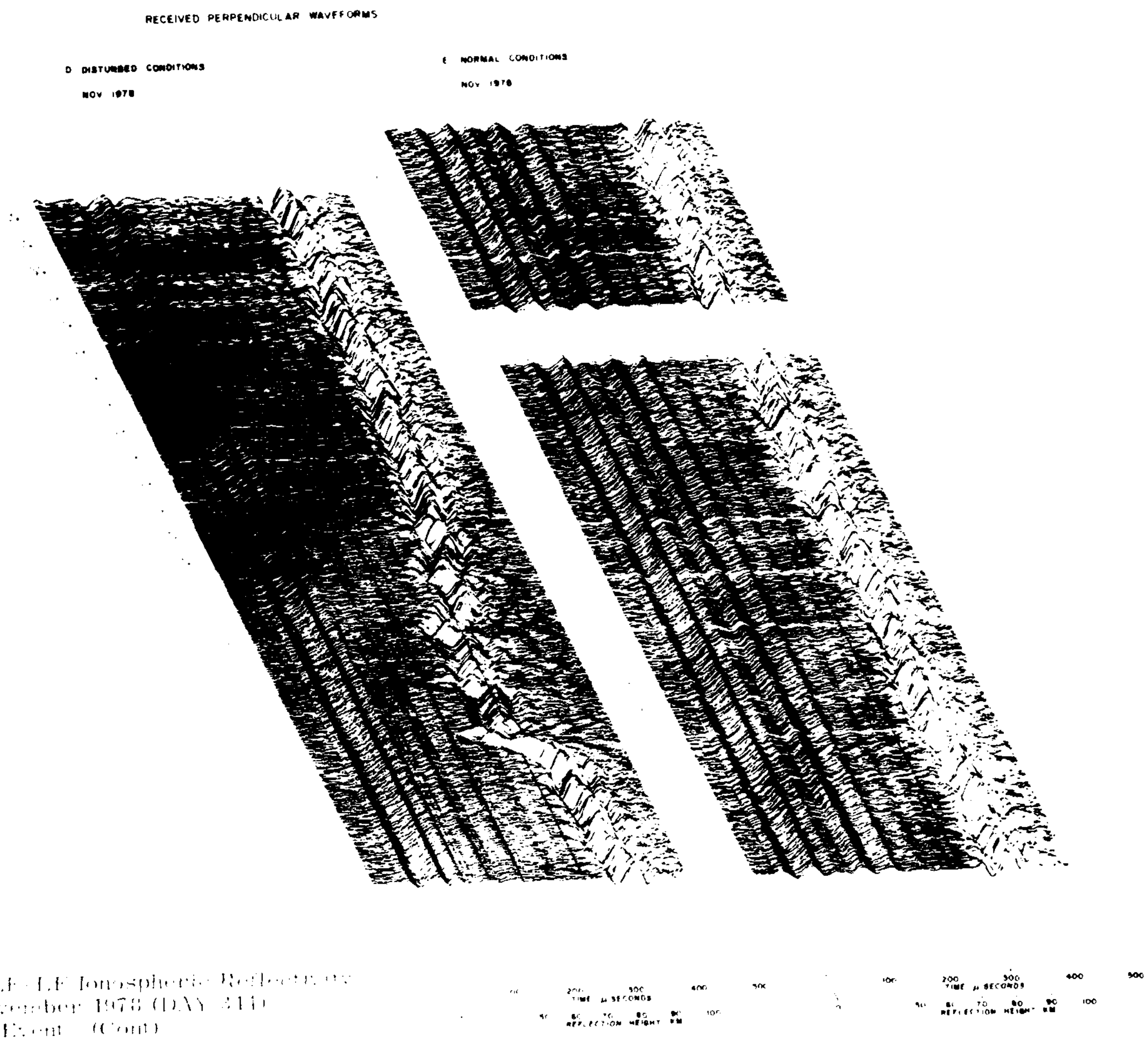


Figure 22. VLF-LF Ionospheric Reflectivity Data for 10 November 1978 (DAY 314) Solar Particle Event (Cont)

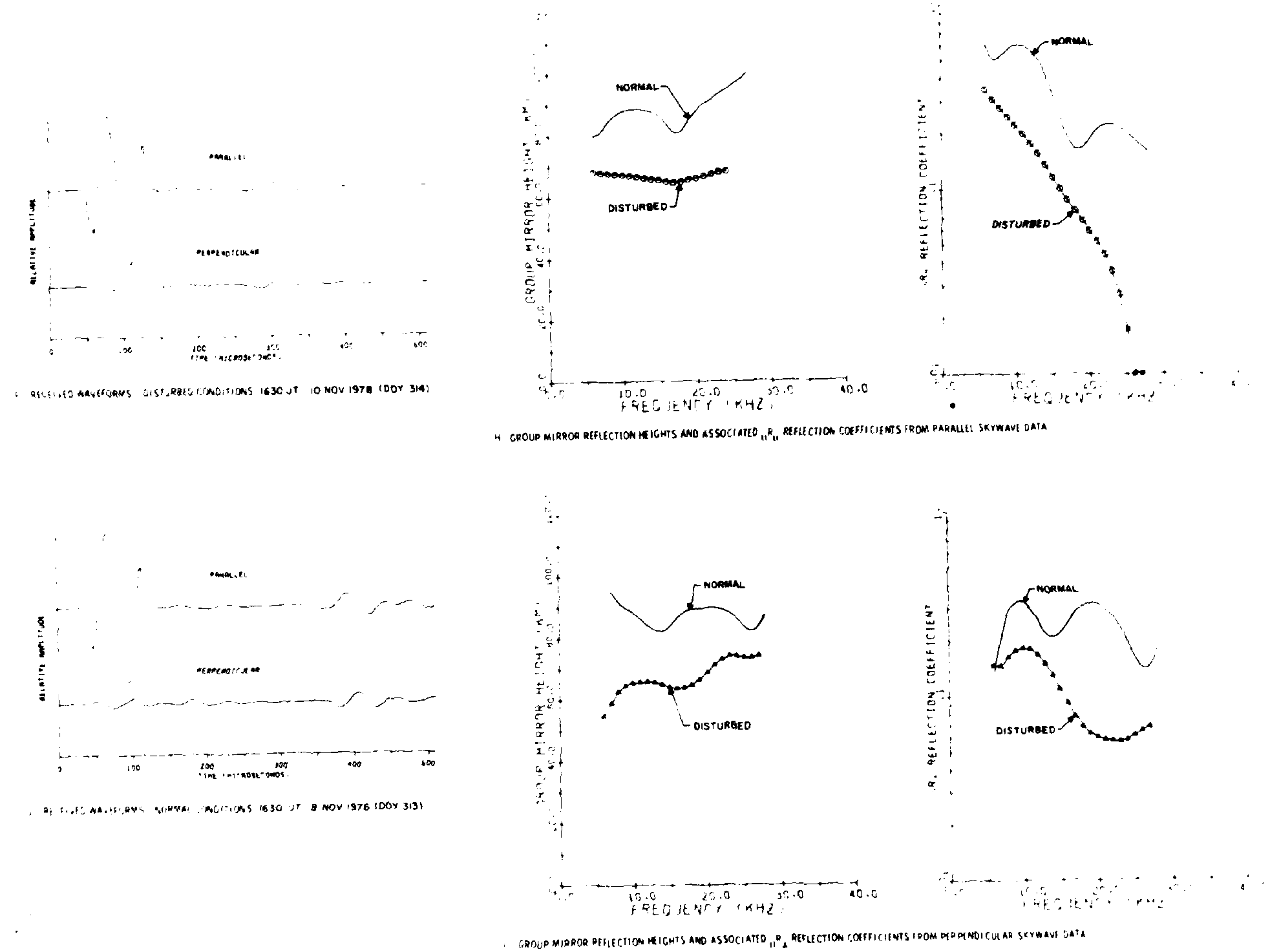
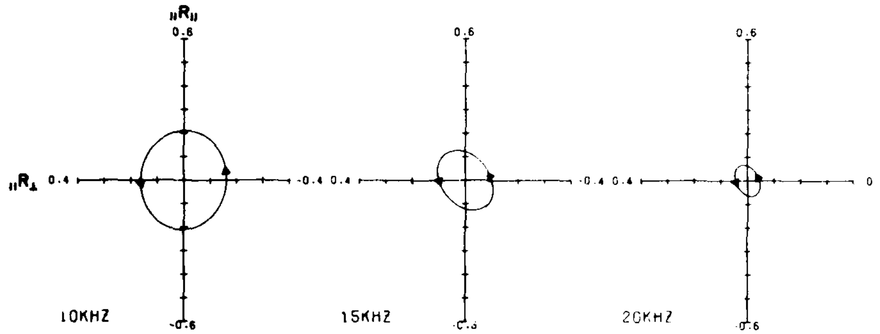
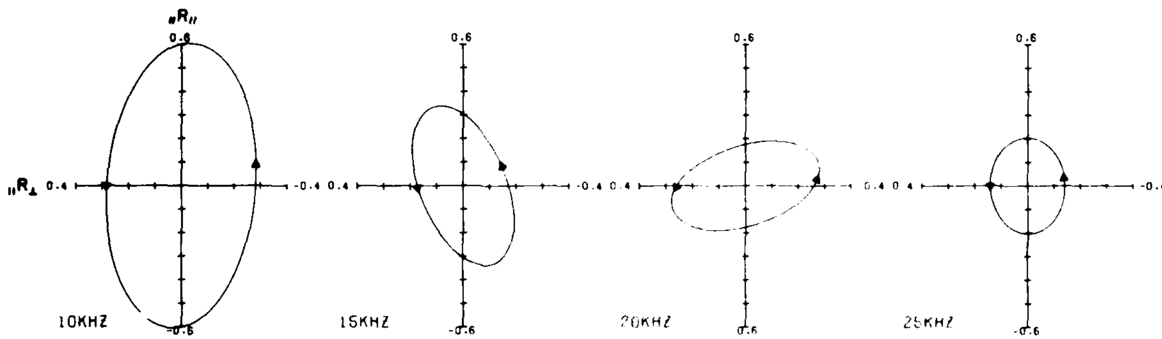


Figure 22. VLF/LF Ionospheric Reflectivity Data for 10 November 1978 (DAY 314) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K. SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 22. VLF/LF Ionospheric Reflectivity Data for 10 November 1978 (DAY 314) Solar Particle Event (Cont)

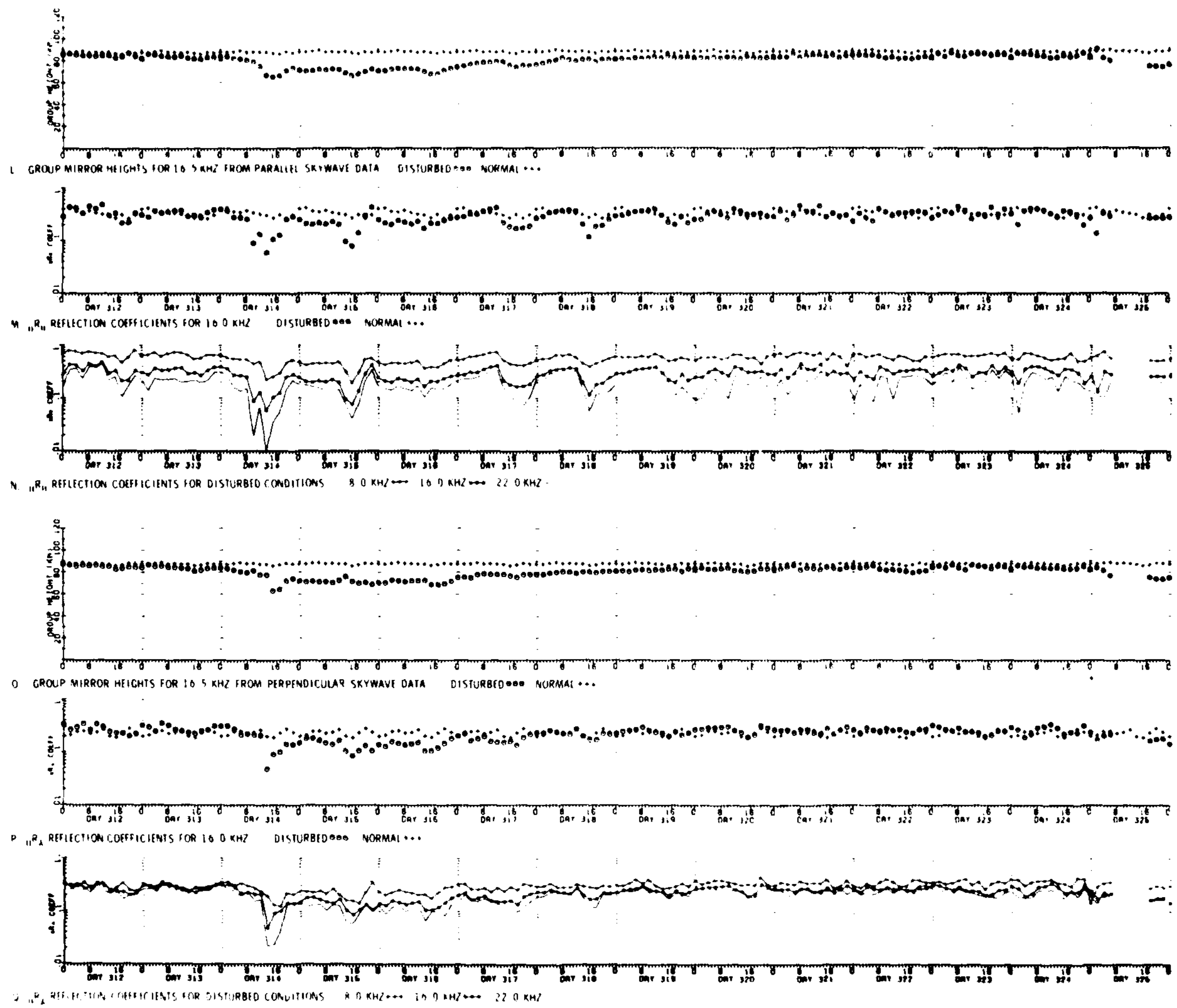


Figure 22. VLF/LF Ionospheric Reflectivity Data for 10 November 1978 (DAY 314) Solar Particle Event (Cont)

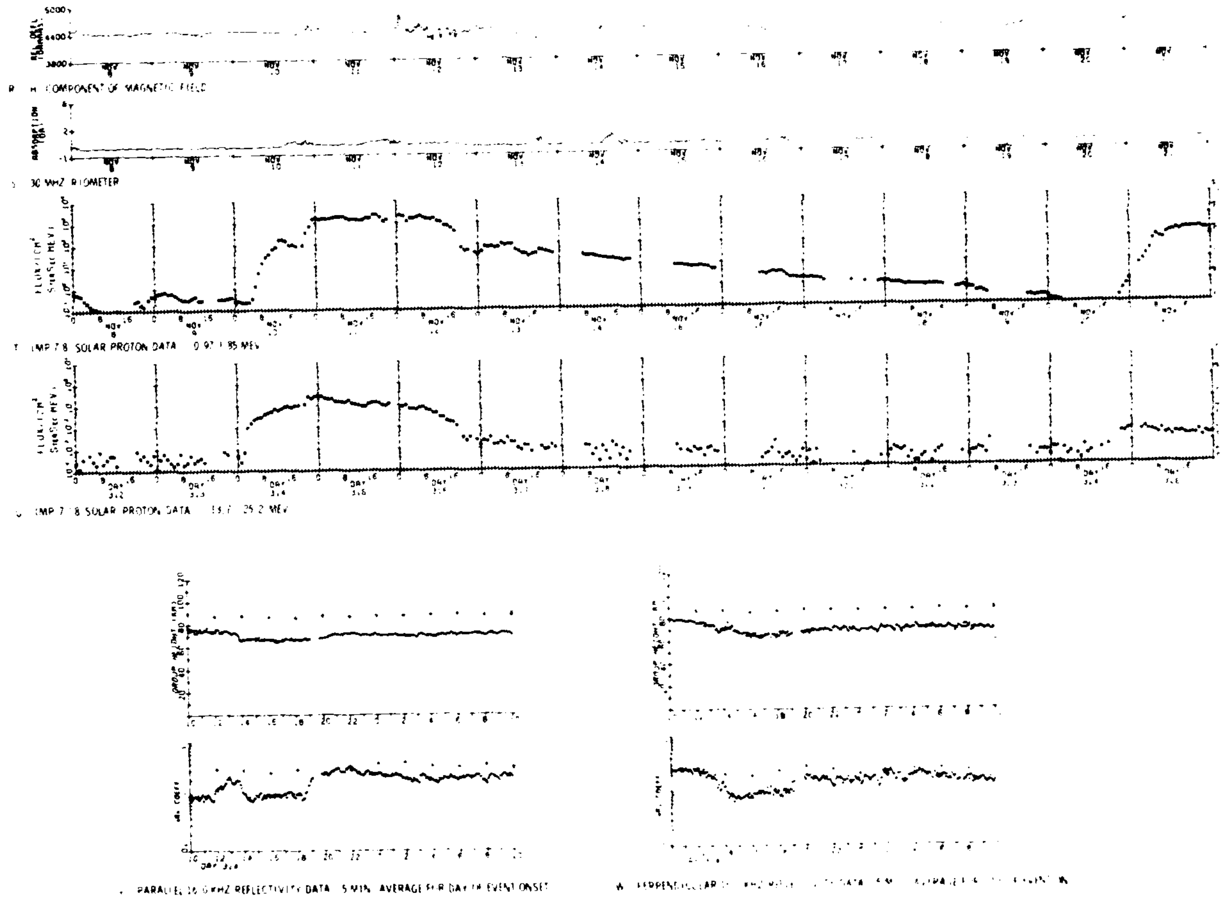


Figure 22. VLF/LF Ionospheric Reflectivity Data for 10 November 1978 (DAY 314) Solar Particle Event (Cont)

11 December 1978 Solar Particle Event

Date:	11 December	Day: 345
Report Figure:	23	
Related Solar Flare:		1807 UT X-ray class: M7
		1833 UT X2
Start of Ionospheric Disturbance:		12 December 0130 UT
Time of Maximum 13-25 MeV Proton Flux:		No data
Maximum Flux:		About 0.1 particle/cm^2 sec sr MeV
Length of Particle Event:		5 days
Lowest 16 kHz Reflection Height:		74 km
30 MHz Riometer Absorption:		< 0.5 dB
Solar Zenith Angle Range:		98° - 126°
Illumination Conditions:		Nighttime

Because this was a polar nighttime event the effects on the propagation parameters were less than would have occurred had this been a daytime event. The minimum 16 kHz H reflection height during the event was 74 km (part L). The 8 April day-night event with a similar particle flux (0.1 particles/cm^2 sec sr MeV) produced a 65-km reflection due to the combined effects of solar and particle ionization. Neither reflection parameter showed a diurnal variation during the 12 December event due to lack of solar illumination.

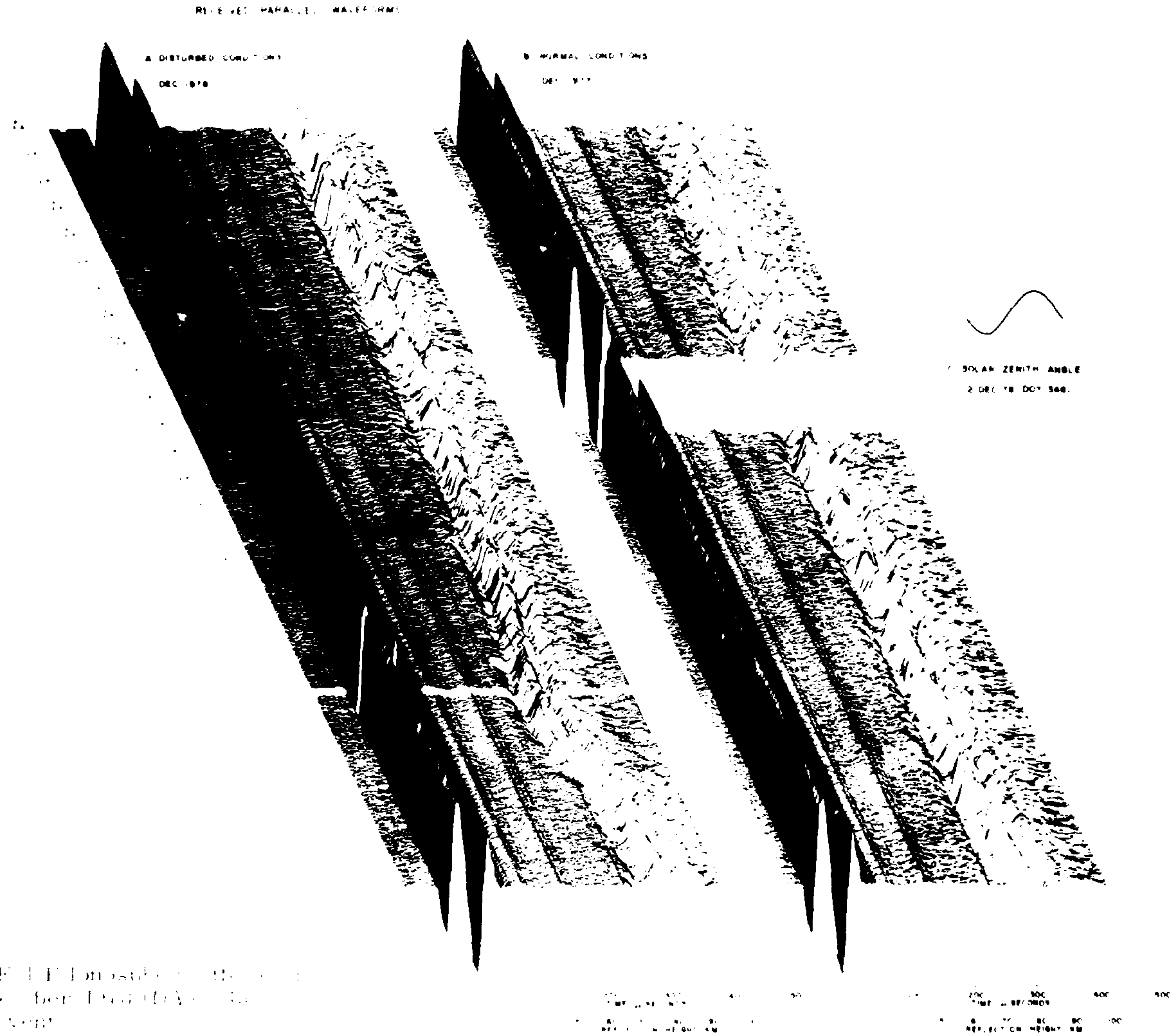


Figure 23. VLF-LF Ionospheric [illegible]
[illegible]
Solar Particle Event

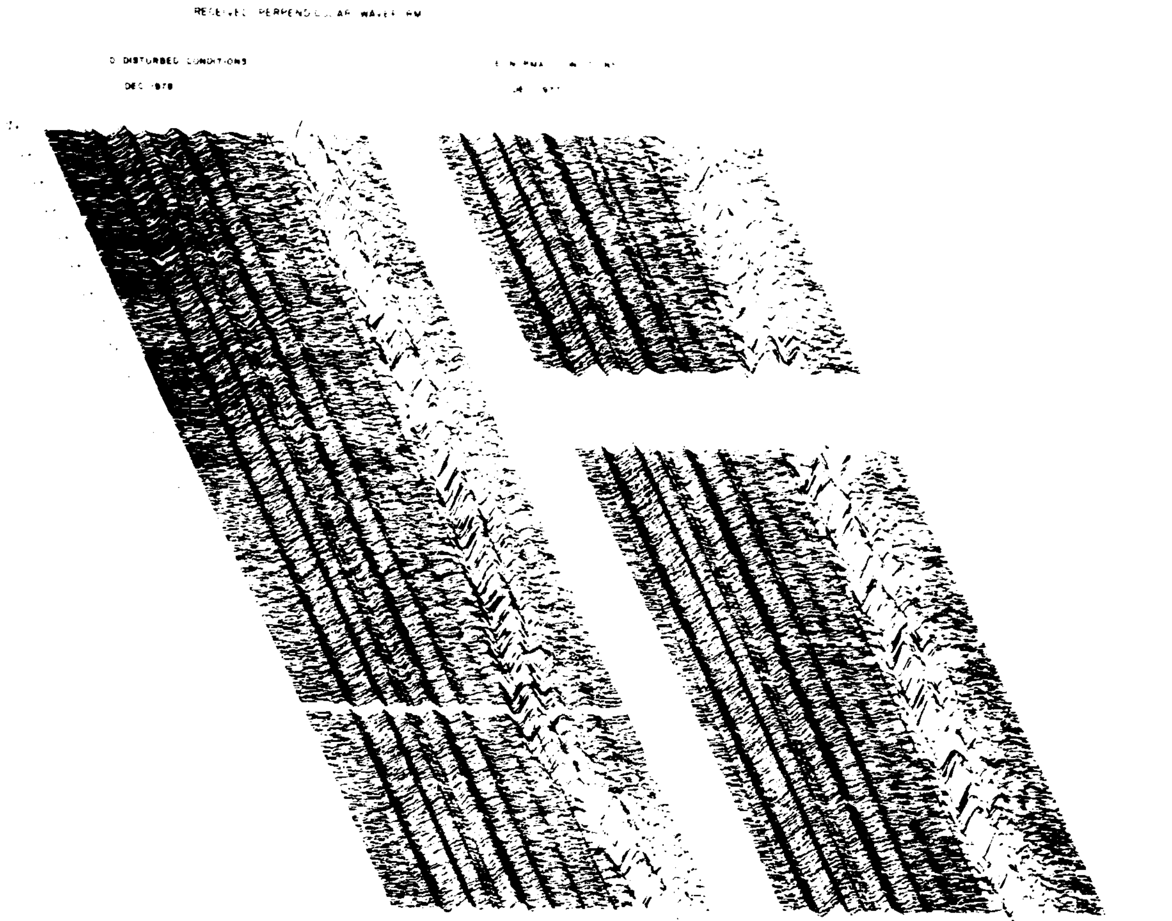


Figure 23. [illegible] LF Ionospheric Response [illegible]
Data for 11 December 1978 [illegible]
Solar Particle Event (PCA) [illegible]

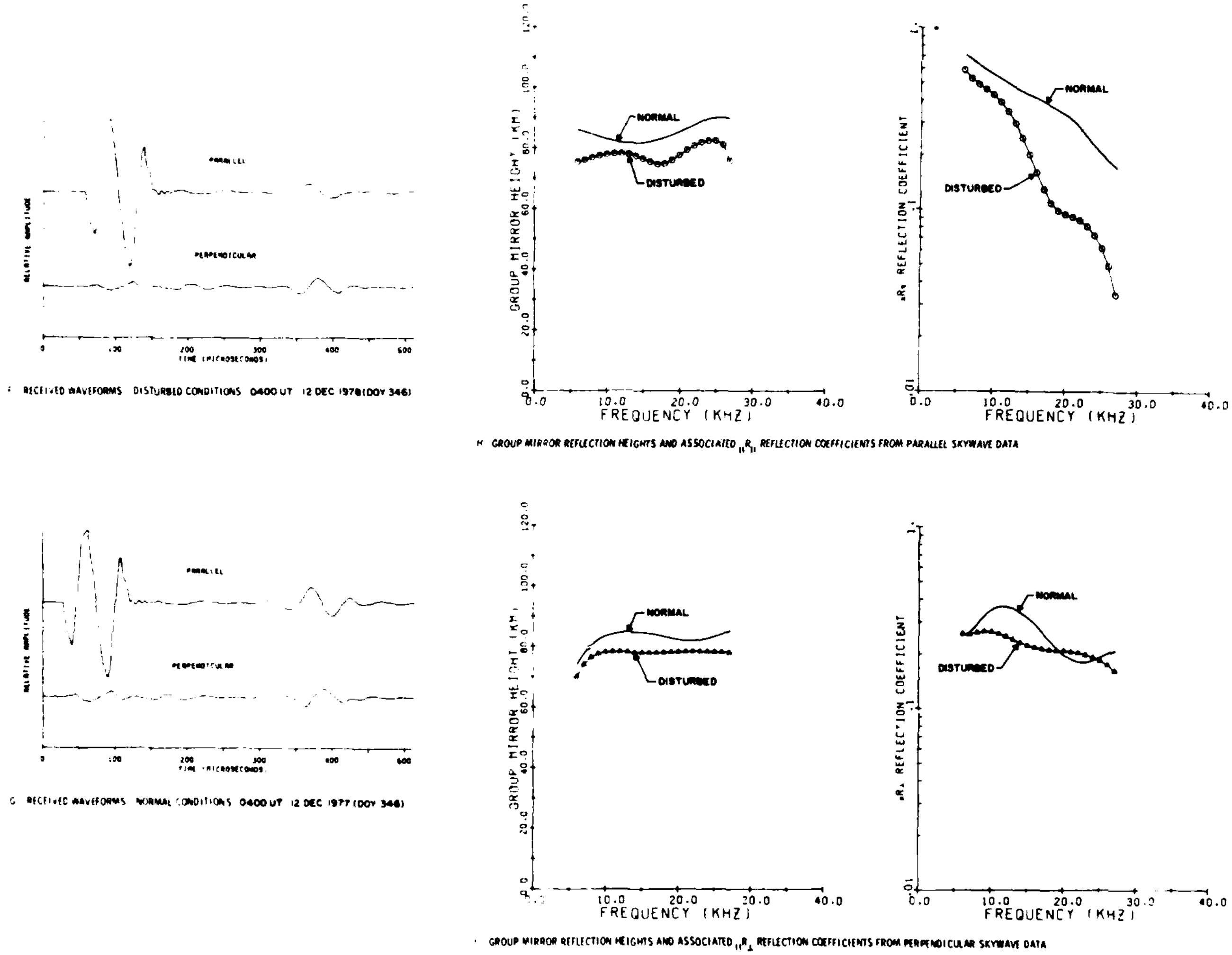
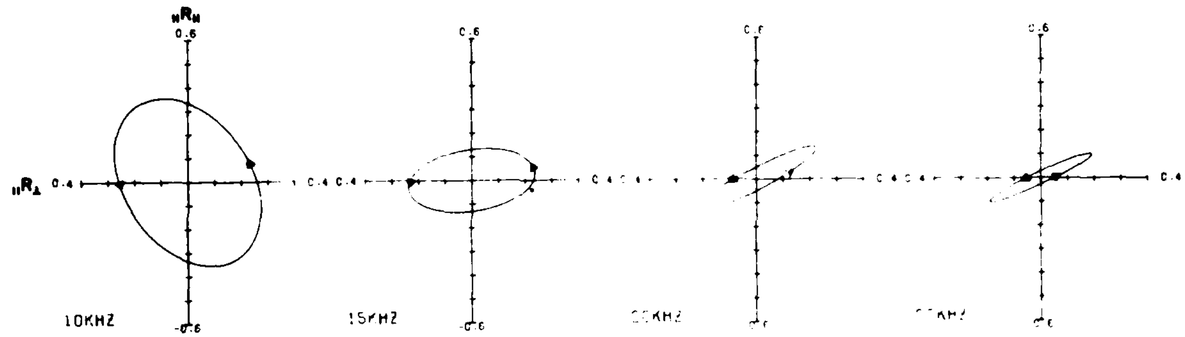
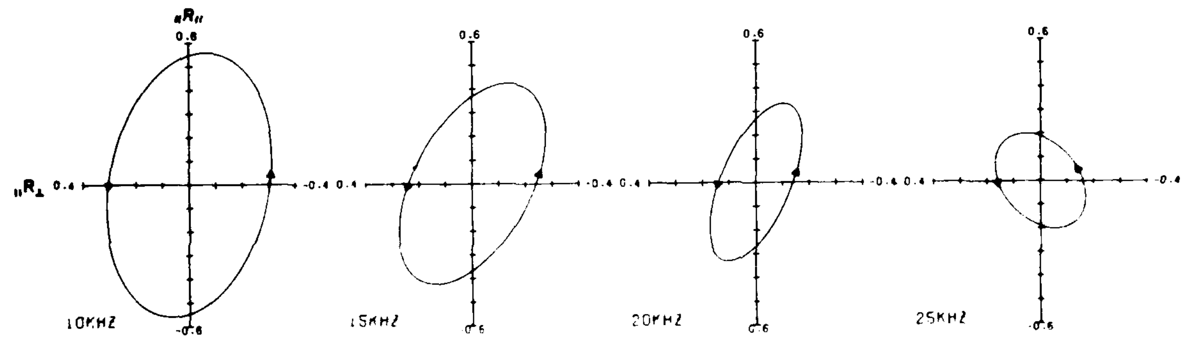


Figure 23. VLF/LF Ionospheric Reflectivity Data for 11 December 1978 (DAY 345) Solar Particle Event (Cont)



J. SKYWAVE POLARIZATION ELLIPSES - DISTURBED CONDITIONS



K SKYWAVE POLARIZATION ELLIPSES - NORMAL CONDITIONS

Figure 23. VLF/LF Ionospheric Reflectivity Data for 11 December 1978 (DAY 345) Solar Particle Event (Cont)

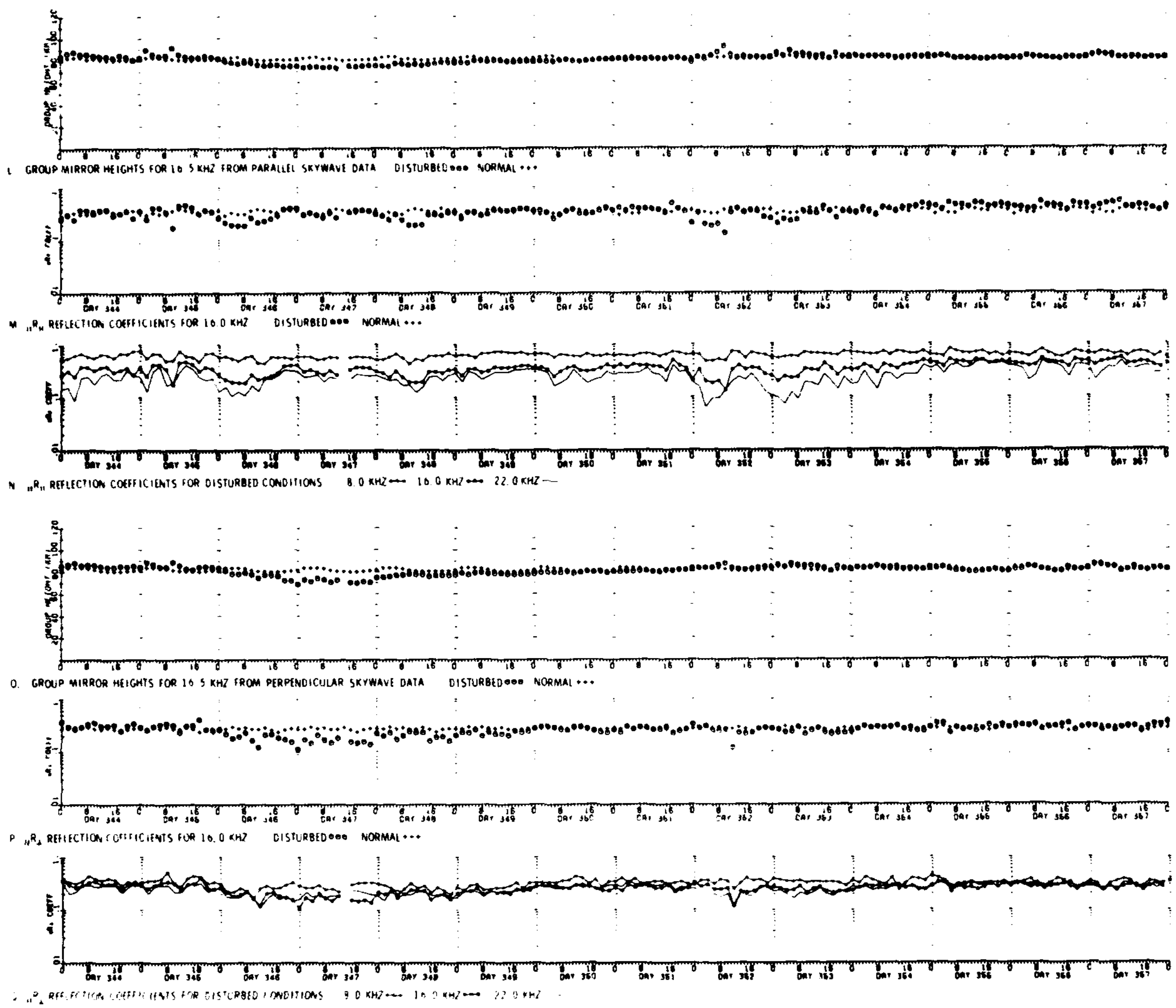


Figure 23. VLF/LF Ionospheric Reflectivity Data for 11 December 1978 (DAY 345) Solar Particle Event (Cont)

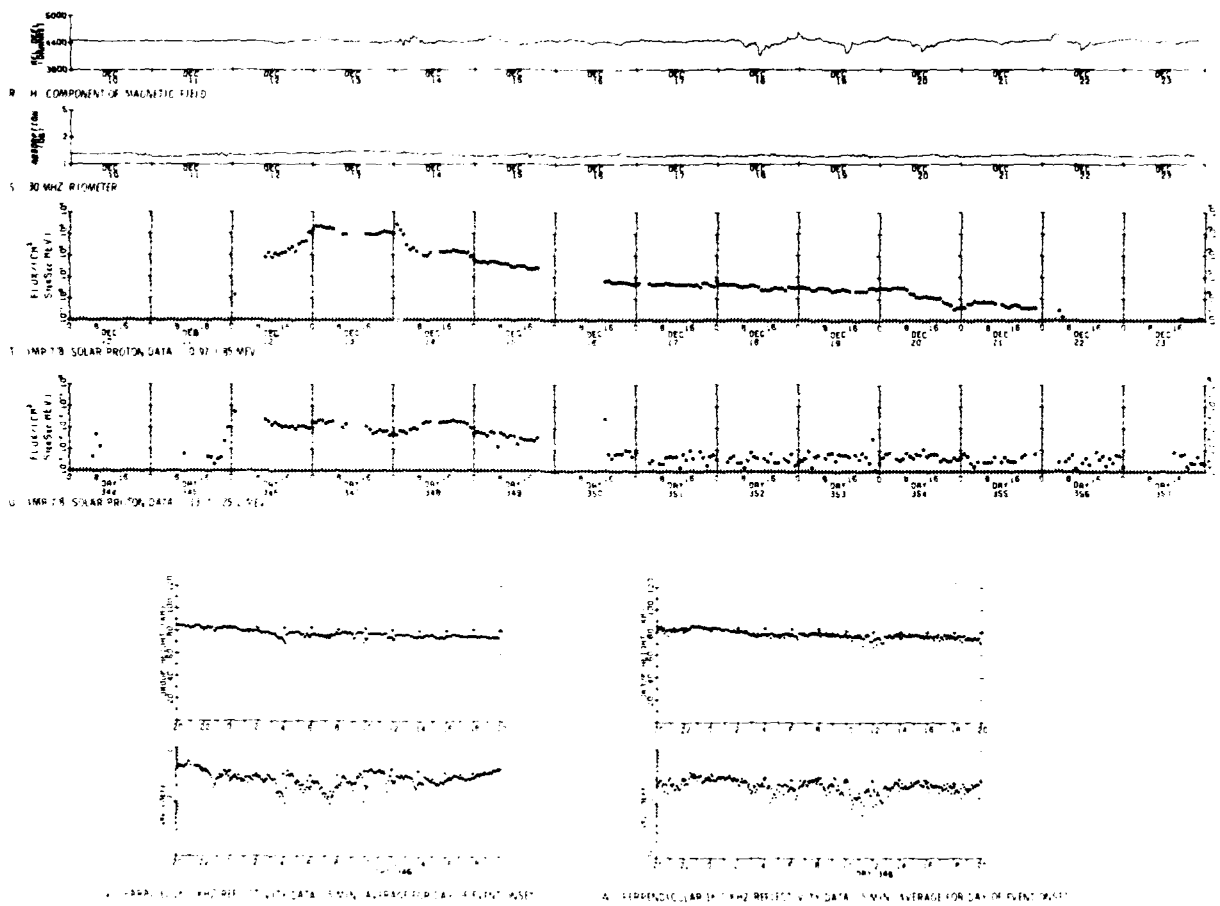


Figure 23. VLF/LF Ionospheric Reflectivity Data for 11 December 1978 (DAY 345) Solar Particle Event (Cont)

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